San Diego Endures Air Quality Hardship: An Investigation for a Culprit

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ES 401-Introduction to Air Quality

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1. Introduction

The United States has skilled pioneering teams of investigators who work to mitigate air quality concerns within the nation's borders. Investigations may launch due to the wealth of technology resources and policy priorities targeted towards cleaning breathable air and maintaining clean air. Breathable air means air in the tropospheric layer of the atmosphere. California, in particular, leads the pioneers towards air quality advancements in the United States and their air is historically in the top worst of the nation. Southern California is notorious for massive environmental events including statewide wildfires. Both smog and wildfires. Wildfires contribute to fine particulate matter ($PM_{2.5}$) polluting breathable air. Fine particulate matter includes liquid or solid particles of a diameter less than 2.5 micrometers.

Fine particulate matter attributes to hashing humans' life expectancy, agricultural yield, and industrial production. As negative implications of $PM_{2.5}$ pollution continue to hinder human existence; more concern for $PM_{2.5}$ air quality episodes has grown. A $PM_{2.5}$ episode occurs when atmospheric concentrations exceed $35ug/m^3$. Air that contains more than this limit exceeds the national standard set by the United States Environmental Protection Agency (U.S. EPA) to protect human health. San Diego, California, encountered such an issue on 21 October 2007 when $PM_{2.5}$ levels in the atmosphere severely surpassed $35ug/m^3$ and remained above the EPA's limit until 28 October 2007. The episode's lowest $PM_{2.5}$ concentration measured in at $36.7ug/m^3$ (US EPA). An assessment of the roots that sprouted the $PM_{2.5}$ episode may aid to alleviate future occurrences and maintain safe air in the region.

Various measurement techniques and new devices allow for an overall perspective about what causes and exasperates air quality issues. Constant air quality monitoring is one means to identify an air quality problem. Monitor sites exist throughout the United States in strategic locations relevant for air quality. Many monitors exist in southern California because of their historical record of air pollution. Fine particulate matter concentrations can be compared over an extended time period to prove that the episode's conditions exceeded average air quality days in a set area. To compliment measured air pollution concentrations, literature reviews also prove to be a useful tool in episode investigation. Publications exist on all topics relevant to United States air quality and build analyses of air quality episodes. Literature reviews provide an exorbitant amount of data and draw conclusions about $PM_{2.5}$ episodes, anthropogenic activity, and significant weather events. Air pollution episodes occur due to a combination of anthropogenic activity and meteorological occurrences creating irregular environmental conditions to an inflicted area. Many activities in the weather can hinder or support air quality on a local, regional, and global scale. Furthermore, meteorology can cause air pollution sources to impact off site states or regions, with no consequence of their own. Because meteorology and air pollution do not recognize political boundaries, a broader set of eyes is needed in order to identify air pollution activity and engagements with the weather. Satellites act as eyes in space that allow for users to examine on a global basis what happens to air pollutants and how regions may suffer from or avoid poor air quality. Technology extends beyond raw satellite data. From monitor, meteorological, and satellite data, computer models can accurately construct what has happened and predict what will happen on a fixed subject, like air pollution. To begin any investigation, the first step is to find out when and where an air pollution episode happened.

2. Where and When the Episode Occurred

Air pollution monitors exist throughout the United States and report air quality conditions around the individual monitors. Being immersed in the air of concern, these devices provide the best assessment of air quality. Therefore, monitors are strategically placed throughout the United States in areas where the air quality needs remediation. California has a plethora of these monitors because of their famously poor air quality, especially southern California. Recent efforts have helped alleviate the air quality issues in southern California. However, the region still combats air pollution episodes on an occasional basis. Fine particulate matter in San Diego rarely reaches levels to pose a threat to public health. Active monitoring sites provide real time data for air quality conditions, as mapped in figure 1. In figure 1, the map of southern California is overlaid with monitors' reports on 23 October 2007. San Diego has four monitors reporting unhealthy $PM_{2.5}$ measured in surface air, indicated by the orange and red dots. This particular day reveals the worst air quality of the episode, having measured $PM_{2.5}$ concentration values reaching 127.1ug/m^3 (US EPA).

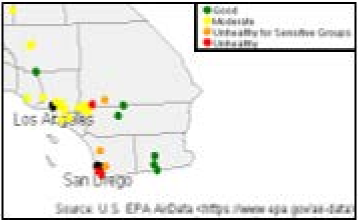

Figure 1: Figure 1 plots air quality monitors over southern California. The severity of the measured air quality and relates values to risk.

San Diego is a dense port region on the southwestern tip of the United States. The county lies along the Pacific Coast and nestles between Tijuana, Mexico, and Los Angeles, CA. All three areas experience similar climates. Their climates have dry and hot summers coupled with cool and moist winters. As figure 1 indicates, monitoring sites in Los Angeles and San Diego vary on the same date and time. Tijuana does not have accessible $PM_{2.5}$ data available for reference. Small geographical displacements can have large variations in air quality, proven in figure 1. Air quality monitors are essential and limited in their abilities for this reason. Assessing monitor data allows for one to know the air quality only within a small vicinity of the monitor. Monitors do not reveal any weather information that may have caused an episode and cannot leave a $PM_{2.5}$ traced path from origin to destination. While limited, the monitors do serve their purpose in exposing bad air quality. Monitors can reveal long term air quality trends with values reported daily.

3. Episode Duration

Long term data trends illustrate when air quality became a concern and may identify trends or reassure an episode is an anomaly. San Diego residents rarely consider themselves vulnerable to threatening $PM_{2.5}$ concentrations because air quality problems are infrequent. Figure 2 highlights episodic conditions in October 2007. Slices of October are red and orange, indicating unhealthy air quality, as it surpasses the U.S. EPA's standard of $35ug/m^3$. A broader look at figure 2 indicates

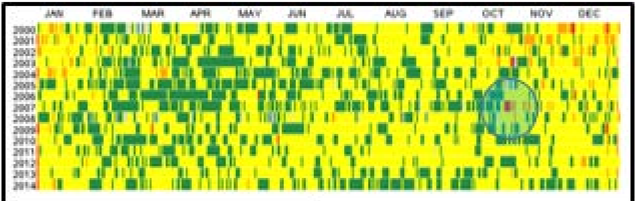

Figure 2: A multiyear tile plot displays air quality monitor values in San Diego, CA. The episode in question is circled in blue.

Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: December 5, 2018

that San Diego has generally clean air and that the October 2007 $PM_{2.5}$ concentrations are unusual. Because the air condition plummeted with a distinct timeframe, one can identify the beginning and end of the $PM_{2.5}$ episode. Locals endured a week-long $PM_{2.5}$ episode, the length of the red and orange slices in figure 2. A critical piece of information to investigate an air pollution episode involves being able to identify the timeframe which episodic conditions persisted over an area. Air quality monitors not only identify current air conditions but also logs all measured data. A historical archive of $PM_{2.5}$ concentrations allows for irregularities to be identified in time and for unveiling air quality trends. Assessing a trend can prove whether efforts to dilute air pollution are effective or futile.

Knowing the duration of an episode is critical information necessary to identify what caused the air quality hindrance. Weather and anthropogenic action that one can identify around the time of the episode may indicate sources or contributors to the poor air quality. Fine particulate matter in the atmosphere commonly derives from volcanic eruptions and forest fires. San Diego does not have volcanic features or consistent wildfires, therefore, these means of $PM_{2.5}$ pollution would not concern San Diego (Westerling et al., 2004). San Diego's $PM_{2.5}$ concentrations rarely exceed $35ug/m^3$ anyways so residents need not threat over forest fire or volcanic activities. The $PM_{2.5}$ episode may have resulted from off location activity that the pollution transferred from. Particulate matter episodes can occur anywhere $PM_{2.5}$ pollution can enter the troposphere, but also anywhere that the debris can travel to, including San Diego.

$PM_{2.5}$ commonly emits from forest fires, common for the California. However, San Diego locals do not regularly endure unsafe $PM_{2.5}$ levels in their breathable air. Air quality monitors here lack the potential to complete the air quality episode investigation. They at least provided evidence that an air quality episode did occur and that it sustained extraordinary $PM_{2.5}$ concentrations for a week. Outside of the monitor data, one can begin to explore what others have already researched and published about the air pollution episode and relating variables. For example, California is known for its wildfires. Literature review concerning California wildfires might intersect at a crossroads of air quality in San Diego. Published material may explore anthropogenic work, meteorological phenomena, or a combination of the two that explains how San Diego developed an air quality episode.

4. Prior Knowledge on Subject

After monitor review, one can specify the duration of an air quality episode. After establishing an episode's timeframe, one may explore what caused the episode. The first step in identifying the $PM_{2.5}$ culprit is to know what has already been investigated regarding the episode. Literature reviews discuss atmospheric conditions in southern California and dissects multiple weather variable behaviors. Southern California has had wind patterns, forest fires, and historical air quality studied to reveal their contributions to poor air quality. Undeniably, San Diego, endured a $PM_{2.5}$ air pollution episode from 21 October 2007 through 28 October 2007. Throughout the episode's duration unusually high wind speeds were reported, believed to be the Santa Ana Wind phenomena (Hutchinson et al., 2018; Schranz et al., 2010). Santa Ana Winds, or "Devil's Breath," conditions involve high wind speeds, extremely low humidity, and follow seasonal patterns; maximizing their speed in autumn months, conveniently when the region is susceptible to wildfires (Raphael, 2003). Wildfires emit $PM_{2.5}$ into the atmosphere. When wildfires outbreak large concentrations of $PM_{2.5}$ among other pollutants are emitted into the atmosphere (Chowdhury et al., 2008; S Viswanathan et al., 2006). Once suspended in the atmosphere, weather conditions can cause $PM_{2.5}$ to be transported away from the emission source (Cao & Fovell, 2016).

Figure 3 maps out the area of the wildfire occurrence and shows evidence of the severe Santa Ana wind conditions (Kochanski et al., 2013). The model may allow for future episodes to be predicted, making the episode's research relevant indefinitely into the future. The Santa Ana Winds prevail southwesterly over the entire Los Angeles, San Diego, and Tijuana coastal region

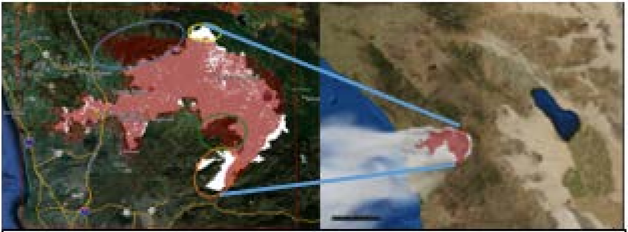

Figure 3: Southern California on 23 October 2007. (Left) A zoomed in view of San Diego's wildfire area, red, and the entire burnt area, white. (Right) Wildfire impacted area from a zoomed out perspective and the smoke travel pattern.

with their travel pattern cloaked in wildfire smoke (Schranz et al., 2010; Zamora et al., 2014). While the land incinerated for days, figure 3 shows the Santa Ana winds carrying the fire's $PM_{2.5}$ emissions over all of San Diego, more than without the severe "Devil's Breath" (Raphael, 2003; Westerling et al., 2004).

The increased Santa Ana Wind speeds and the October wildfires brew the perfect storm to emit and disperse $PM_{2.5}$ over San Diego in late October 2007 (Schranz et al., 2010). One can determine that the severe and irregular environmental patterns would have the ability to produce $PM_{2.5}$ episodic conditions in San Diego (Corbett, 1996).

5. Meteorological Conditions

After reviewing literature published on San Diego air quality events and related topics, we have a better understanding of what may have attributed to the episode. Literature reviews may pertain to this specific episode, or may allow for further understanding of certain mechanisms that could have contributed to an episode. Reviews cover the Santa Ana Wind trends and October weather conditions in San Diego. Now that others have determined related environmental events relevant to air quality, Santa Ana Winds and wildfires can examined further to show their potential impact on San Diego. Publications have established a working knowledge of the Santa Ana Winds and wildfires. After learning what has already been accomplished in an air pollution episode, one can explore meteorological variables more in depth. Literature reviews of Kochanski, et al., 2013, for example uncover that wind speeds matter greatly. After determining meteorological causes of the air quality episode, one can investigate the weather variables further to understand if patterns exist or other external factors caused the weather pattern shift. A variety of weather models can be employed in looking at wind patterns, for instance, the Hybrid

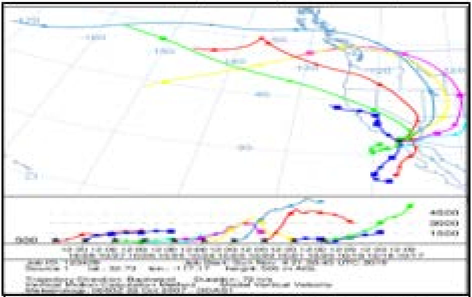

Figure 4: HYSPLIT model shows backward wind trajectories from San Diego, CA from 21 October 2007 until 28 October 2007 (Stein et al., 2015).

Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) shows wind direction patterns over a desired location. The model, shown in figure 4, shows exceptionally strong Santa Ana Winds prevailing from the northeast, from over Nevada and Utah, which are known origins for the wind phenomena (Cao & Fovell, 2016; Shekar Viswanathan et al., 2006).

Figure 4 demonstrates the Santa Ana Wind motion and how San Diego lies directly under its path. Such a wind trajectory would carry the polluted air from the forest fires and impact San Diego air quality, as figure 3 illustrates. Although the Santa Ana Winds regularly blow over Southern California and Northern Mexico during the fall, their severity is what threatens the region's air quality. (Bolinski et al., 2016). Each wind trajectory in figure 4 originate at San Diego. By 28 October 2007, the winds reach their endpoints on the model. This trend relates to the Weather Research and Forecasting (WFF) model in figure 3. Both pieces of evidence support the air quality monitors and give cause to their high $PM_{2.5}$ readings.

As part of an air pollution episode metrological assessment, one should explore the weather reports during the episode to determine if any other weather variables contributed to the public health concern. Throughout the weeklong San Diego episode, average temperatures resided at 70^{0}F. Before the episode, temperatures scaled to the high 60s and after the episode, temperatures retreated to the low 60s. The temperature change may be evidence of the incoming Santa Ana Winds blowing in warmer air over San Diego and out over the Pacific Ocean. In addition to temperature, one should also investigate precipitation to validate air quality impacts by weather. Before, during, and after the $PM_{2.5}$ episode, San Diego had no recorded precipitation. Remember, dry and warm air characterizes Southern California in the fall (Shekar Viswanathan et al., 2006). Little precipitation reported by Weather Underground is consistent with dry conditions and regularly coincide with the Santa Ana Windstorms during the fall season.

6. Satellite Perspective

The HYSPLIT analysis in figure 4 and WRF model in figure 3 effectively highlight the Santa Ana Wind effect on the October wildfires. Fires produce a large quantity of smoke, ash, and dust into the atmosphere. They may settle onto the ground or reside in the air, both either away from or at the emissions source, thus increasing the concentrations of $PM_{2.5}$ over a potentially large plot of land (Viswanathan et al., 2006). Now that meteorological variables have been identified through literature reviews and modeling confirming those findings, one has a working knowledge

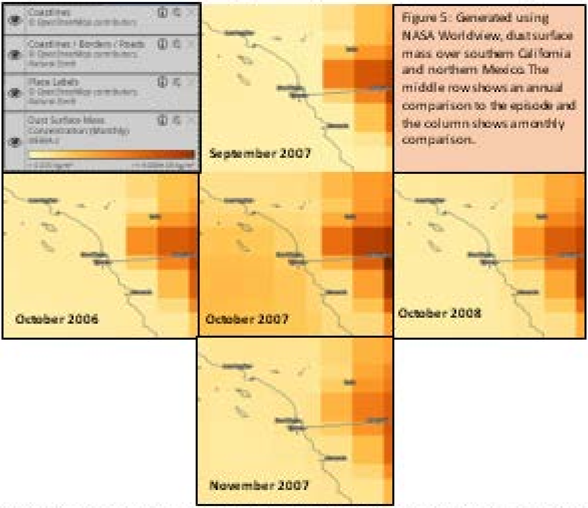

Figure 5: Generated using NASA Worldview, dust surface mass over southern California and northern Mexico. The middle row shows an annual comparison to the episode and the column shows a monthly comparison.

about what caused the air quality episode in San Diego. In order to confirm existing research and connect to modelled data, satellite data must be referenced for yet another perspective over the episode. Figure 5 reveals the importance of using satellite data in the air pollution investigation. The center image in figure 5 shows a monthly average of dust surface mass concentrations. Darker colors indicate denser concentrations while paler shading indicates little dust. On the left and right of the center image are one year comparisons before and after October 2007. The satellite imagery shows that October 2007 had much higher dust content over Southern California and Northern Mexico. The images above and below the center image compare dust content one month before and one month after the 2007 air quality episode. Preceding and following months and years to the October episode spike have little dust content identified by satellite, reinforcing the modeling, publication, and monitor data. Satellite data allows for an even broader picture about the extent of damage poor air quality poses to earth. Figure 5 shows October 2007 provided a dramatic amount of dust over the Pacific Ocean. Air quality monitors do not exist over the ocean, therefore, air quality data becomes discontinuous over the majority of the world. Satellite data bridges the gap in understanding by being able to monitor the entire surface. Connecting air quality trends on a global basis is necessary because regional air pollution contributes to tainting global air quality.

Satellite data is not limited to measuring matter in the atmosphere, but also for collecting weather information. Literature reviews and models have identified wind patterns as key contributors to poor air quality over San Diego from 21 October 2007 through 28 October 2007. Wind trends can amount from satellite technology.

Figure 6 uses satellite data to record wind speeds. The center image highlights wind speeds in the month of the $PM_{2.5}$ episode. Referencing the scale on the top left side of figure 6 indicates that the darker blue colors are mild winds and as the color yellows, the Santa Ana winds become more severe. From the left to right of the center image are satellite collected wind speeds for the years previous to and following the episode in 2007. Satellite images above and below the center image portray that the months before and after the air pollution episode experienced relaxed winds compared to the center image. This satellite data is consistent with figure 3, showing a severe forcing of dust and smoke over San Diego and extended into the Pacific Ocean. Higher wind speeds trace the same pattern as the dust in figure 3, but with a greater area recorded. Like the dust content imagery, satellite data allows for weather variables to be traced on a broader area for a more certain understanding about variable patterns, such as wind.

Fall in San Diego historically has maintained low humidity, creating dry airspace that is prone to have large wildfires. In fall months that the Sana Ana Winds are high, the south west coast of California becomes a threat to $PM_{2.5}$ (Raphael, 2003). As shown in Figure 6, in a month with as high wind speeds as October 2007 are causes to suspect that the Santa Ana Winds reached an infrequent high and may exasperate annual issues, such as wild fires. More than air pollution concerns may be addressed by satellite data. Glacial melting, global heating or cooling, and solar radiation are only three examples of extended applications of improved satellite technology. Satellites not only provide a larger scale insight into global processes but also provide a versatile arsenal of information rather than using a device limited to measuring only one weather variable or limited to a small radius to apply measurements.

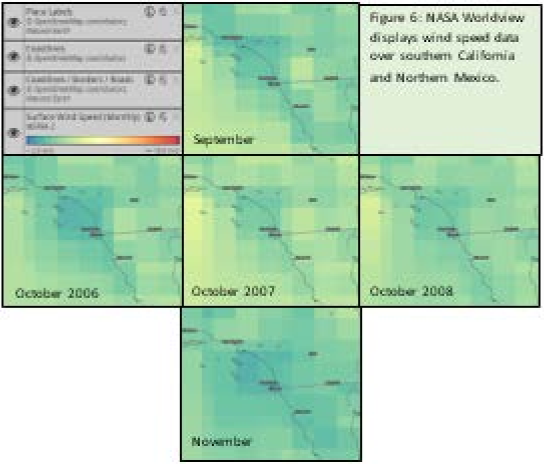

Figure 6: NASA Worldview displays wind speed data over southern California and Northern Mexico.

7. Conclusion

Satellite technology creates more access to more knowledge about earth's natural processes. Figures 5 and 6 prove this statement as they provide measurements of San Diego, the entire southwestern corner of the United States, and even over the Pacific Ocean. Data collection and observation with satellites continues to improve as the world finds value in their ability. Satellites watch earth from afar, versus being an in situ mechanism for taking measurements. While satellites by themselves may not guarantee the most accurate description about what happens on earth, they continue to improve and can prove their validity when compared to other measurement methods. The satellite data shows both increased wind speeds and increased dust concentrations over San Diego, similar to other measurements taken.

Figures 3 and 4 support the satellite imagery, as the results all support conditions for an air quality episode to emerge. Figure 3 shows a detailed visual of how the wildfire smoke's path was impacted by the Santa Ana Wind pattern. The HYSPLIT model in figure 4 reveals that southwesterly winds pass over San Diego, directly over the path of and during the timeframe of the wildfires in October 2007. Reason to create the models and extrapolate from publications relevant to San Diego air quality have purpose because monitoring stations collect continuous data and indicate when air quality becomes an issue.

Air quality monitors populate the United States in a sporadic manner. They are limited by their placements and can only report air quality at the station. Installation and upkeep are expensive, so installing monitors to create continuous data over the entire United States would be unrealistic. Instead, the monitors that are active have certain justification for where they are. Monitors may be placed in regions with historically poor air quality, or exist where preserving healthy air quality is paramount. Figures 1 shows the usefulness of the monitors but also their limitations, as air quality is only certain where the monitors are placed. However, figure 2 illustrates how monitor data over extended periods of time reveal air quality trends and irregularities. This information allows for the population to know their air quality any day. A long term record of measurements also may prove that human efforts to mitigate air pollution have a positive impact. For example, figure 2 tells that San Diego regularly experiences clean air. Any episodic event is obvious because of the limited occurrences.

San Diego's $PM_{2.5}$ air quality episode becomes more transparent with measurement data collected from multiple devices and continuously improved modelling. From October 21 2007 through 28 October 2007, San Diego's air quality tanked because $PM_{2.5}$ concentrations amplified. An abundance of $PM_{2.5}$ infiltrated the air from inland wildfire debris. Fires emit smoke, ash, and dust which all increase the amount of $PM_{2.5}$ in the air. While the fires expelled fine particle debris, the Santa Ana Wind pattern displaced the smoke and dust. The Santa Ana Winds sometimes become unusually strong. When the 2007 wildfires engulfed the air in smoke, the winds blew the smoke over San Diego and out over the Pacific Ocean.

San Diego's air quality episode proves how multiple perspectives at the same problem can reveal different players in what caused the event. Individually, one platform of investigation does not give enough support to prove what caused an air quality problem. However, when different angles are considered and compared together, a more full understanding of a pollution problem prevails. Air quality monitors, publications, models, and satellite technology are only a few examples of different measuring and observation technologies relevant for air pollution studies. Improved technology and weaving data together improves air pollution understanding, including the causes and impacts of an episode. An increased use of technology in the future and mastery should be important to everyone on earth for the wealth of potential information about global processes and the benefits are shared worldwide.

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