A Tool for Retrospective Analysis of High Air Pollution Events
FINAL REPORT

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1. Abstract

In high-pollution areas, local air districts must optimize the use of finite resources to protect public health. A crucial part of this effort involves prioritizing mitigation; air quality "exceedances" that are policy-remediable must be chiefly pursued. Conversely, "exceptional events", which are "not reasonably controllable or preventable," should take lower priority. For particulate matter (PM), this distinction requires the evaluation of multiple parameters, which are often consulted separately by air quality analysts. Before now, a unified tool that quickly summarizes the cause(s) of an exceedance had not been developed.

We synthesized various PM indicators into an app for the use of experts at South Coast Air Quality Management District (South Coast AQMD). To address PM values, we first collected online data from continuous and filter-based instruments. This was supplemented by meteorological data; a mesonet token was used to access wind speed, wind direction, and precipitation parameters. Using the client's knowledge of regional PM trends, we identified six broad regions with unique pollution characteristics. PM and meteorological values were aggregated by the user's regional selection, as well as the chosen time range. Tabs with value tables, time-series plots, and other useful data displays were populated according to these choices. All together, the app includes the following tabs: (1) Home, (2) PM, (3) Wind, (4) Rainfall, (5) Combined Analysis, (6) Historical PM, and (7) Satellite Imagery.

Our final product maximizes user-flexibility to provide a multivariate analysis of air quality exceedances. Moreover, as a single streamlined tool, it enhances the efficiency of air quality controls to defend the public from detrimental PM health effects.

2. Introduction

The South Coast Air Quality Management District (South Coast AQMD) is home to some of our nation's worst air pollution. Every year, major portions of Los Angeles, Riverside, San Bernardino, and Orange counties--which fall under South Coast AQMD's jurisdiction--struggle to maintain federal standards designed to protect the health and safety of their combined 17 million residents (South Coast AQMD, n.d). A notable culprit of the region's hazardous air quality is PM10; this refers to airborne particles whose diameter is less than 10 micrometers. The miniscule size of PM10 (about the width of a human hair, and smaller) makes this pollutant especially lethal to human and environmental health. Particles permeate tissue membranes, and can disrupt the functions of major organ systems. This links PM10 to aggravated cases of asthma, respiratory failure, early on-set Alzheimers, heart attacks, and critical developmental issues (CARB, n.d). In the environment, tiny yet powerful PM10 particles block the photosynthetic structures of crops and other plants we rely on (CARB, n.d). With such high stakes, PM10 must be monitored and managed efficiently.

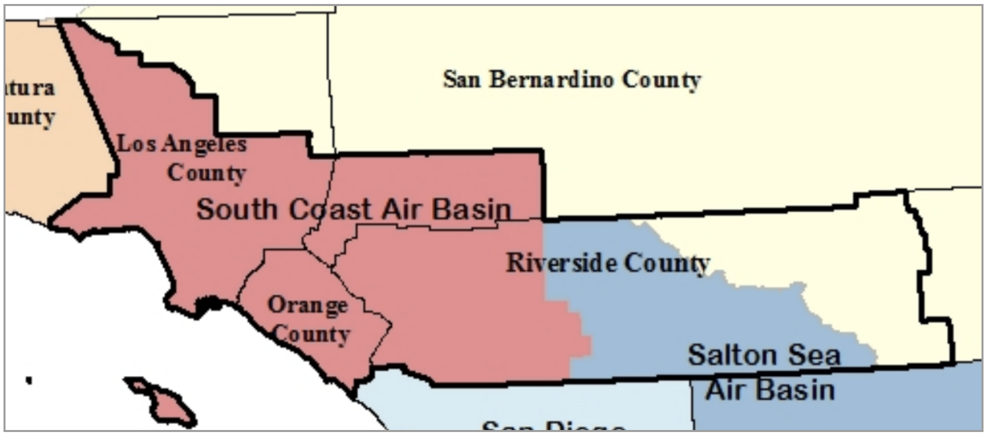


Figure 1. Map of South Coast AQMD's jurisdiction

In partnership with the South Coast AQMD, our practicum team aimed to streamline the recording process of events which exceed the federal PM10 standard. The main objective of our app was to distinguish "exceptional" PM10 exceedance events (which are not reasonably controllable or preventable) from other PM10 exceedances that can be mitigated through policy (EPA, 2019). PM10 "Exceptional events" are caused by external, ungovernable factors such as wildfire smoke, firework shows, and most notably– suspended dust due to high winds. Since they cannot be controlled by the district, exceptional events are "red herrings" for policy enactment. Therefore, they must be subtracted from thresholds used to trigger control measures (SCAQMD, n.d). Through the development of an analytic MATLAB tool, our team created software that synthesizes meteorological, satellite, and other forms of data to summarize the causes of a PM10 exceedance. This way, air quality analysts can isolate exceptional events, dedicate productivity to the exceedances they can control, and deploy measures necessary to protect the public from PM10. Our app will help South Coast AQMD determine why a PM10 exceedance occurred and if it was influenced by uncontrollable or not preventable events.

3. Background

3.1 Regulatory Systems Governing Air Pollution

a. Criteria Pollutants, NAAQS, and Air Pollution Regulatory Structure

The National Ambient Air Quality Standards (NAAQS) were created in order to protect the public health and welfare from hazardous pollutants. The NAAQS are limits on six common air pollutants that are known to have harmful effects on public health and the environment, and come from numerous and diverse sources (Environmental Protection Agency (EPA), 2021a). There are two types of national ambient air quality standards: primary and secondary standards. Primary standards protect public health, including the "health of 'sensitive' populations such as asthmatics, children, and elderly," whereas secondary standards protect public welfare, including "protection against decreased visibility and damage to animals, crops, vegetation, and buildings" (EPA, 2021b). In addition, the NAAQS are defined by four elements: the indicator, averaging time, level, and form (Integrated Science Assessment (ISA), 2019). The indicator is the pollutant that will be measured, the averaging time is the time over which the air quality measurements should be obtained and averaged or cumulated, the level is the air quality concentration used to determine if the standard is achieved, and the form is the air quality statistic that is compared with the level when determining whether an area meets the standard (ISA, 2019).

Both the primary and secondary NAAQS for inhalable particulate matter (PM10) is 150 µg/m3, with an averaging time of 24 hours. If PM10 levels surpass this value throughout the day, an "exceedance" is recorded for the local air district (EPA, 2021b). Furthermore, the recorded number of "exceedances" at a monitor determines whether an air district has violated the NAAQS. A "violation" is evaluated over a three year period, and occurs when the average number of exceedances surpasses 1 per year (EPA, n.d).[1] When local air districts "violate" the NAAQS, a series of regulatory responses called "contingency measures" begin. According to SCAQMD supervisors, such responses include "developing clean air plans", "detailing controls that will bring [the district] into attainment by applicable deadlines", and implementing "rules, incentive programs, and other emission controls" (Epstein & Rees, S, 2021). Reports are sent up the chain of command, first to the California Air Resources Board (CARB), and then to the Environmental Protection Agency (EPA) (California Air Resources Board, n.d). Consult Figure 1 for a visual representation of this process.

Figure 2. EPA's process of recording exceedances and violations.

b. The 2016 Exceptional Events Rule

Given the extensive response to air quality violations, The EPA's 2016 Exceptional Event Rule evaluates exceedances to control for "exceptional events." Exceptional events cannot be controlled or prevented, so it would not make sense to use monitoring data influenced by exceptional events when making regulatory decisions. Therefore, these data can be excluded when determining compliance with a standard (California Air Resources Board, n.d.).

In order to be considered an exceptional event, the event must meet three requirements. The event must have affected the air quality in such a way that "there exists a clear causal relationship between the specific event and the monitored exceedance or violation," was not "reasonably controllable or preventable," and was a "human activity that is unlikely to recur at a particular location or was a natural event" (Treatment of Data Influenced by Exceptional Events,

[1] Note: Not every monitor measures PM10 daily. Some measure every third day, while others measure every sixth day. Due to the longer collection interval, these measurements are weighted more heavily. An exceedance at a 6-day monitor could violate the federal standard despite there being only one exceedance in the three year period. (Treatment of Data, 2016)

2016). When determining if an event was not reasonably controllable or preventable, the air agency must demonstrate that reasonable measures to prevent the event and reasonable measures to control the impact of the event were applied at the time of the event (Treatment of Data, 2016). When determining if an event was a human activity that is unlikely to recur at a particular location, recurrence is defined as three events in three years, counting backwards from the date of the most recent event. Exceptions to this benchmark of three events in three years could be made on a case-by-case basis. EPA regional offices are to decide on the boundaries that characterize “a particular location” (Treatment of Data, 2016). Finally, a “natural event” is defined as an “event and its resulting emissions, which may recur at the same location, in which human activity plays little or no direct causal role” (Treatment of Data, 2016). This means that anthropogenic sources that are reasonably controlled will not be considered to play a direct causal role in emissions. If the event has satisfied all of these requirements, the data can be excluded when determining exceedances and violations.

The EPA sets specific guidelines governing the incidence of wildfires and windblown dust as exceptional events. Wildfires can be considered exceptional events if evidence shows that the wildfire directly affected monitors, causing the measured exceedance. The concentration of PM10 on the day of the wildfire may also be compared to historical data to demonstrate a causal relationship. Furthermore, prescribed fires (caused by humans) that turn into wildfires “may be eligible for treatment as an exceptional event” (EPA, 2019). Events involving windblown dust may be considered exceptional if (1) “the dust entrained by high winds is transported to the monitoring site”, (2) “ wind speeds in the source region are high enough to pick up natural soils or overwhelm reasonable controls on anthropogenic sources”, AND (3) the sustained wind speed is greater than the high wind threshold (25 mph for western states, including California) (EPA, 2019b).

3.2 PM10: Sources, Formation, and Causes of Episodic Pollution

a. PM10 and PM2.5

Particulate matter (PM) is an air pollutant composed of extremely small, solid particles and liquid droplets (Anderson et al., 2011). According to the CARB, particles vary widely in chemical composition, and are not usually made of a single pollutant. Rather, they are a complex mixture of many chemical species including “ inorganic ions, metallic compounds, elemental carbon, organic compounds, and compounds from the earth’s crust” (CARB, n.d). This includes well-known particle substances such as soot, smoke, acids, soils, mineral dust, and gaseous pollutants (EPA, 2004). In regulatory practice, PM is defined by the length of its diameter. Particles with an aerodynamic diameter of 10 microns or less (PM_{10}) are considered inhalable, and can cause adverse health effects by disrupting the functions of major cardiovascular, respiratory, and neurological systems (Anderson et al., 2011; Schulte et al., 2021). A subset category of PM10 consists of “fine” particles whose diameters are less than 2.5 microns (PM2.5)(CARB, n.d).

b. Causes of Episodic/Exceptional PM10

When investigating exceedances of the national PM10 standard, analysts of South Coast AQMD distinguish "exceptional" events (which are not reasonably controllable or preventable) from other PM 10 violations (Schulte et al., 2021). Unlike those that are routine and planned for, "exceptional events" occur episodically, and are often caused by external, ungovernable factors outside of the agency's control. Although episodic air quality events rarely influence long term PM10 averages, they test the limits of public short-term exposure, "briefly pushing hourly and daily PM levels into the unhealthy ranges of the Air Quality Index" (EPA, 2004). The South Coast AQMD identifies three types of such events in its 2021 maintenance plan: wildfires, wind-blown dust, and fireworks (Schulte et al., 2021). In particular, wildfires and wind-blown dust have their own "carve outs" in the 2016 Exceptional Event Rule, which sets parameters for their incidence as "exceptional events" (see section 2.1, subsection ii).

i. Wildfires

In Southern California, the onset of Santa Ana winds (SAWs) are associated with the region's most toxic PM10 emissions (Aguilera et al., 2019). This occurs through both local and northern-driven mechanisms of wildfire smoke dispersion. The heat and dry air of SAWs can exacerbate ignitions, spurring wildfires. This is a major source of fine particulate matter (PM2.5) (McClure and Jaffe, 2018). Not only do particles deteriorate air quality within the SCAB, PM10 arising from the combustion process was found to be especially toxic when compared to equivalent concentrations of ambient particulates (Dreary and Grifffths, 2021). This enhanced toxicity is due to the presence of free radicals (Aguilera, 2021), and chemical toxins such as Polycyclic Aromatic Hydrocarbons (PAHs) and benzene (Dreary and Griffiths, 2021).

ii. Wind-blown dust

Another cause of episodic high PM10 levels in the SCAB is windblown "fugitive" dust (Schulte et. al, 2021). According to the EPA, dust events are caused by "the passage of weather fronts" through arid climate regions, and are typically " dominated by large, coarse [PM10] particles" (EPA, 2004). In Southern California, this primarily manifests through SAWs (Aguilera et al., 2019). To control for anthropogenic (human-made) fugitive dust sources, the South Coast AQMD enforces Rule 403. The rule requires that large operations (defined as "projects greater than 50 acres and/or more than 5,000 cubic yards of daily earth-movement") notify South Coast AQMD, "implement specific control measures", and "maintain recordkeeping" of dust source activity. Despite regulatory efforts, "ground disturbances, geological conditions, or meteorological conditions" may result in episodic PM10 that exceeds federal standards, causing "chronic nuisances" to public health (Schulte et al., 2021).

iii. Fireworks

Each year, episodic PM10 exceedances occur on July 4, July 5, and January 1st (Schulte et al., 2021). These conditions arise from the use of fireworks (and other pyrotechnic displays) which emit numerous PM10 precursors. The production of firework color involves a "high temperature ignition of different metal compounds." This reaction gives rise to PM10 that dramatically inflames mammalian lungs. Furthermore, in an in-vitro study on mouse lung tissue, Hickey et. al found that samples exposed to July 4th Anaheim conditions evoked the "highest reactive response" (Hickey et al., 2020). Researchers point out that toxic PM10 emissions in the area are likely associated with Disneyland, which resides in the SCAB (Hickey et al., 2020).

3.3 Health Effects of breathing PM10

Particulate matter can harm human health. In fact, people with heart or lung diseases, children, and the elderly are the most vulnerable groups that are affected by particulate matter exposure ("PM10," 2021). PM2.5 exposure caused 4.2 million deaths globally and 103.1 million disability-adjusted life-years (DALYs) in 2015. These numbers represent 7.6% of total global deaths and 4.2% of global DALYs, with 59% occurring in east and south Asia (Cohen et al., 2017). Considering all the health risks that come from exposure to PM2.5 and PM10 (which includes various types of pulmonary problems and fatal diseases), regions with high levels of PM experience high numbers of serious health cases related to particulate matter exposure.

Short-term health impacts of PM10 include difficulty breathing, coughing, eye, nose, and throat irritation, chest tightness and pain, fatigue, and general respiratory discomfort. Long-term exposure to PM10 can result in even more serious health problems like lung tissue damage, asthma, heart failure, cancer, adverse birth outcomes, chronic obstructive pulmonary disease (COPD), and premature death ("PM10," 2021). Exposure to PM10 can impact child health outcomes, for example, an increase in PM10 level can increase the risk of neonatal mortality by 6% according to an analysis based on 23,954 births in India (Mahapatra et al., 2020).

Like any other region that is exposed to high amounts of particulate matter, Southern California experiences numerous respiratory problem cases. Between 1993 and 2014, the Southern California Children's Health Study (CHS) showed that out of 4,140 children, about 525 were identified with incident asthma. Particulate matter plays a significant role in the development of childhood asthma which we can see through the following data: for PM2.5, the incident rate ratio (IRR) for asthma was 0.81 for a median reduction of 8.1 $\mu g/m^3$, with an absolute incidence rate decrease of 1.53 cases per 100 person-years. For PM10, the IRR was 0.93 for a median reduction of 4.0 $\mu g/m^3$, with an absolute incidence rate decrease of 0.46 cases per 100 person-years (Garcia, 2019). We can also see on the following Figure 3 that a greater reduction in asthma incidence rates was observed in communities with larger decreases in PM2.5 concentrations. For PM10, results were less consistent.

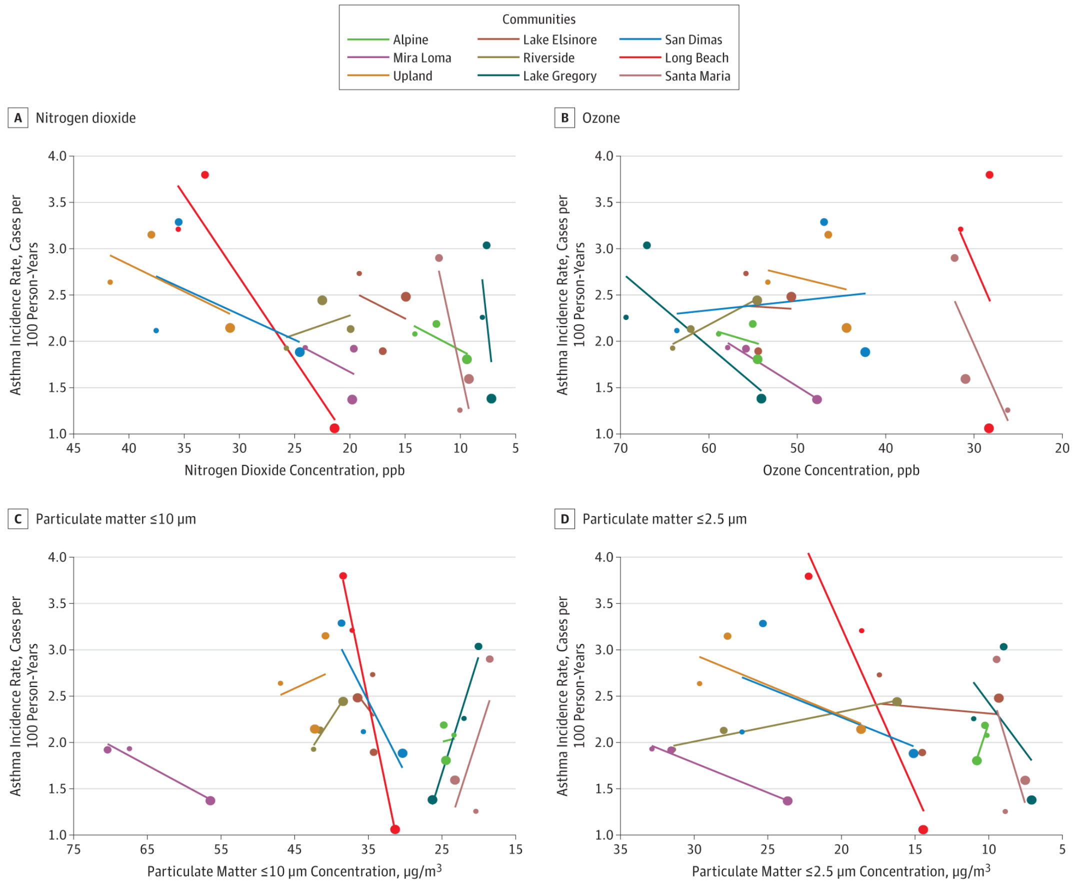


Figure 3. Asthma Incidence Rates and Air Pollutant Concentrations in 9 Communities During the 1993-2001, 1996-2004, and 2006-2014 Cohorts of the Southern California Children's Health Study, 1993-2014.

3.5 Satellite Data

The complex and pronounced effects of PM10 and airborne dust in different regions around the world require satellite-derived, *in situ*, and modeled measurements to understand their properties and effects. This project primarily utilizes satellite-derived measurements to obtain measurements of PM10 and airborne dust. A common parameter used by satellites to measure aerosol concentrations such as PM10 is aerosol optical depth (AOD) (Stirnberg et al., 2018). AOD is related to the amount of light that is scattered or absorbed by aerosols in the atmosphere. The relationship between AOD and PM10 concentration largely depends on relative humidity, wind speed and direction, and boundary layer height (the lowest part of the atmosphere in a region) and therefore is highly variable regionally and seasonally (Stirnberg et al., 2018). AOD is an accurate proxy for PM10 concentrations only under certain conditions: (1) if the atmosphere is relatively dry (with a relative humidity between 30 to 50 percent) and (2) the boundary layer height is between 600 to 1200 meters (Stirnberg et al., 2018). Other uncertainties surrounding satellite-based PM10 measurements include the fact that AOD cannot be observed under cloudy conditions. AOD products may also be biased due to snowy or sandy terrain, or cloud readings could also mistake it for clear conditions (Saleh et al., 2017). Nonetheless, AOD is an accurate proxy given that the aforementioned optimal conditions are true at the time a measurement is taken (Stirnberg et al., 2018).

AOD measurements can be derived from different types of algorithms, the two most widely known algorithms being the Dark Target (DT) and Deep Blue (DB) retrieval algorithms. DT measures light scattered by aerosols against a dark-colored surface to separate the aerosol and surface signals (hence its name). DT is therefore advantageous to use when aerosols are observed over dark surfaces such as oceans and dark-colored land but not over ocean glint or bright-colored land such as deserts, cloudy areas, ice-covered or snow-covered land ("Dark Target Basics", n.d.). On the other hand, the DB algorithm measures aerosol and surface signals at a specific wavelength. Aerosol signals are often difficult to differentiate from surface signals in the visible light range, but in the 412 nanometer band, or "deep blue" band, aerosols appear to be bright and surface features dark (NASA, 2015). DB can be used for both bright-colored and dark-colored surfaces, thereby having increased spatial coverage compared to DT. However, DB is not employed over water (NASA, 2015). A third, more recently developed algorithm, the Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm, provides higher resolution images of 1 kilometer (Lyapustin and Wang, 2007). It is designed to work with Moderate Resolution Imaging Spectroradiometer (MODIS) data, discussed below, and simultaneously retrieves atmospheric aerosols and bidirectional reflectance. It can detect clouds and correct atmospheric effects over both dark vegetated and bright desert surfaces (Lyapustin and Want, 2007). Because such algorithms are developed differently, the produced results may vary among sensors.

In general, another advantage of satellite-derived measurements is that the vast network of satellites provide data over wide spatial ranges on a consistent basis depending on the satellite used. Therefore, satellite data is particularly useful for rural or remote areas that do not have *in situ* measurements (Stirnberg et al., 2018). Satellites also have varying spatial resolution (the smallest area that can be analyzed by a satellite), temporal resolutions (the time it takes for a satellite to revisit and collect data at the same location), and orbits (whether a polar-orbiting satellite provides data for the entire Earth or a geostationary-orbiting satellite travels at the same speed as the Earth and provides data for only one geographical location). As the study conducted by Emili et al. demonstrates, data products from different satellites can be used for PM10 measurements at different temporal and spatial scales depending on the topic of interest (Emili et al., 2010).

Satellite data also has its disadvantages. Nearly all sensors that have monitored aerosols such as PM10 during last decades are on polar orbiters, limiting the spatial range and making the readings for certain locations discontinuous (Saleh et al., 2014). In such cases, measurements from ground stations could be utilized instead if available. Data of certain satellites can also have relatively low spatial and/or temporal resolution, and cloud cover could potentially hinder the processed data (Stirnberg et al., 2018; Park et al., 2020). Furthermore, sensor differences such as available wavelengths, width of sensor bands, sensitivity, algorithms such as DT or DB, and calibration differences can contribute to different results (NASA, n.d.).

There is a large variety of satellite data products for PM10, which usually come as AOD products. Common sources of AOD products include the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard the Terra and Aqua satellites, the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor aboard the Suomi NPP and NOAA-20 satellites, and the sensors on the Landsat 7, 8, 9 and satellites currently in operation. MODIS data has a relatively high temporal resolution of 1 to 2 days but a lower spatial resolution of 250 meters, which precludes its use for small or medium cities (Alvarez-Mendoza et al., 2019). On the other hand, Landsat 7 data in particular has a lower temporal resolution of 16 days but a higher spatial resolution of 30 meters (Alvarez-Mendoza et al., 2019). Another satellite that is useful for PM10 measurements is the Geostationary Operational Environmental Satellite (GOES), a stationary satellite employed by the United States for real-time weather monitoring (NASA, n.d.). GOES satellites that are currently in operation are the GOES-West and GOES-East satellites, the latter of which is commonly used to spot wildfires and track smoke. Other satellites that provide useful AOD products include the Multi-angle Imaging SpectroRadiometer (MISR), Advanced Very High Resolution Radiometer (AVHRR), and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) sensor (Voinea et al. 2017).

3.6 Methodologies used to measure PM10 concentrations

Federal Reference Methods (FRMs) and Federal Equivalent Methods (FEMs) have strict guidelines and performance criteria they must meet to produce viable data. FRMs and FEMs are developed for a specific standard for a specific criteria pollutant, PM_{10} in this case, and are only considered samplers once they have successfully passed all the necessary testing and analysis protocols (Hall et al., 2014). FRMs and FEMs work by drawing in ambient air at a specific flow rate into an inlet where the particulate matter will be separated by size (Code of Federal Regulations, 2006). In this case, the particulate matter within the PM_{10} size range will be separated onto a different filter during the sampling period (Code of Federal Regulations, 2006). The FRM filters are measured before and after they are used. FEMs on the other hand do not require weighing because they are continuous. Scientists are then able to determine the difference in mass due to the collected PM10. They will then calculate the total volume of the air sampled which they will then use to calculate the concentration of PM_{10} (Code of Federal Regulations, 2006). PM_{10} can then be calculated by dividing the total mass by the total volume (Code of Federal Regulations, 2006).

A sampler is defined as a Federal Reference Model if and only if the sampler's design and specifications meet the set guidelines and rules the EPA has for FRMs (Clements & Robert, 2019). The EPA's measurement and design principles for PM_{10} FRMs ensure that all instruments are up to caliber (Clements & Robert, 2019). They are designed to produce the most "fundamentally sound and scientifically defensible" PM_{10} concentration measurements (Clements & Robert, 2019) and are in theory supposed to set the example of what successful air pollutant measuring instruments look like. FRMs set a basis for comparison when the EPA is reviewing new possible FRMs and FEMs (Clements & Robert, 2019). Even though they can be used interchangeably, FRMs are more commonly used by states and other monitoring organizations (EPA, 2021).

According to the EPA, the FRMs are the “gold standard” of air pollution monitoring instruments because they ensure quality data, reliability, and accuracy (EPA, 2021). The biggest advantage of FRMs is that they ensure the data is collected in the same manner every single time, no matter the site (EPA, 2021). FRMs also provide a high level of precision, are reliable and accurate, and the set specifications help reduce costs.

Air pollution measuring instruments considered FEMs are tested with the same samplings and technologies as FRMs (EPA, 2021). FEMs have a bit more freedom to be created in any way the manufacturer sees fit if it meets the requirements established by the EPA. However, FEMs should still provide a comparable level of compliance as an FRM when making decisions regarding the NAAQS (EPA, 2021). Potential samplers that did not meet every single qualification for the FRMs can be referred to as a FEM by the EPA if they met the requirements for PM_{10} air pollution samplers in general (EPA, 2021). FEMs incorporate new technology that has yet to be seen in existing instruments (EPA, 2021). FEMs advance new technologies, foster innovation, and help bridge the necessity of PM_{10} concentration results (Hall e.t. al, 2014).

FRMs and FEMs both have advantages and disadvantages. FRMs must follow a strict design protocol as well as follow the general rules of ambient air samplers (Clements & Robert, 2019). FEMs can be built in any way as long as they still meet EPA’s ambient air sampler guidelines (Clements & Robert, 2019). Regardless of the methodology, accurate PM_{10} concentration measurements are essential. FEMs and FRMs provide data to determine PM_{10} concentration trends on a national and universal level, evaluate how effective current pollutant control strategies are, help set national guidelines and rules, and help ensure the safety of the public (Clements & Robert, 2019). Just like any other technology, FRMs and FEMs could use improvement to ensure quality within all samplers.

3.7 Meteorological Parameters

a. Important meteorological parameters that drive high PM10 concentrations

Many variables affect the concentration of particulate matter (PM), including anthropogenic sources such as agricultural operations, industrial processes, combustion of wood and fossil fuels, and construction and demolition activities. Natural sources include airborne soil, pollen, material from volcanic eruptions, and particles formed from natural gaseous precursors. In addition to anthropogenic and natural sources, meteorological parameters can affect the concentration of PM because air movement influences the concentration of air pollutants. Meteorological parameters include variables such as pressure, temperature, wind speed, and humidity that researchers can use to predict the weather. When the air is quiet and contaminants are unable to disperse, their concentration rises. Conversely, strong, turbulent winds remove pollutants quickly, resulting in reduced pollutant concentrations. Furthermore, there are different sizes and concentrations of PM, between 2.5 and 10. Important meteorological parameters that drive high PM_{10} concentrations include relative humidity, precipitation, sunshine duration, temperature, and wind speed and direction. Zhao et al. (2019) studied and compared the relationship between meteorological parameters, PM_{10} concentration levels, and the air quality index using Spearman correlation coefficients. They found that even with the same pollutant source, the degree of pollution differed greatly due to different meteorological conditions. The correlation analysis was used in this study to explore the impact of meteorological factors on the ratio of PM_{10}. Referencing previous studies and the different approaches to finding correlations, Zhao et al. (2019) discovered that "decreased PM_{10} concentration with the accumulation of precipitation owing to wet scavenging is an essential removal pathway of air pollutants". The results of the Spearman correlation analysis showed "the positive influence of precipitation on PM_{10}", which implies that wet scavenging is more effective for coarse particles rather than fine particles." They also noted that when there is high wind speed, it has the advantage of eliminating air pollutants, and when long periods of high sunshine occur with high wind speed, this condition also negatively affects the PM_{10} concentration. An exception to this trend is when high winds entrain dust. By contrast, a decrease in relative humidity is frequently accompanied by short periods of sunshine, cloudiness, and windless weather, all of which contribute to an increase in pollution, with relative humidity having a more significant negative impact on PM_{10} than $PM_{2.5}$.

4. Research Questions

Our design process was governed by three questions:

1. What type of datasets make a compelling case for exceptional events?
2. How can we use AppDesigner (a subprogram of MATLAB) to display data effectively?
3. What is the best way to design a graphical user interface (or GUI) for air quality experts?

5. Methods

5.1 Environment used to develop the tool

As per the client's preference, our analysis tool was programmed using MATLAB's AppDesigner. This format is compatible with existing infrastructure at South Coast AQMD and will ensure seamless integration for use by the agency. Apart from this, MATLAB contains several key features necessary for the functionality of our product. First, the software includes enhanced data loading capabilities, which accommodates numerous meteorological sources (AQI measurements, wind speed, satellite data, etc). MATLAB also has conditional coding features (if.. else) which can be used to isolate and evaluate exceedances for further analysis. Also, MATLAB's exporting features are universal. The software packages webapps for effortless sharing between users. Finally, MATLAB software is freely available through UCLA, so no costs were necessary.

AppDesigner is a subprogram of MATLAB. Its software allows programmers to design an interface (including buttons, switches, pull-down menus, plots, etc) and write the code that controls its behavior. Once implemented, controls on the guided user interface (GUI) operate through "callbacks." Our team customized these features to locate and display the causes of a PM10 exceedance. Aside from customization, AppDesigner presents the benefit of being modular. This allows for the tool to be assembled incrementally, granting us the ability to identify coding mishaps throughout the design process.

Given our limited experience with MATLAB (and AppDesigner), our first objective was to complete software training. All team members completed a 2-hour, web-based "onramp" (MATLAB & Simulink Tutorial, n.d.) and a short interactive tutorial provided by the software (MathWorks, n.d). In addition, the team studied "How to Build a GUI in MATLAB using App Designer" (MathWorks, 2020) on Youtube and "Getting Started with AppDesigner"(*AppDesigner Overview Video*, n.d).

5.2 Data Collection

a. PM Data

We gathered continuous PM measurements from airnow.gov. We pulled both PM_{10} and $PM_{2.5}$ hourly data from this site. These monitors are useful for understanding the general air quality trends in an area because measurements are updated often. However, continuous monitors are not EPA-approved, so they cannot be used for regulatory purposes. We gathered filtered-based PM measurements from the EPA AirData site. We used the PM10 Mass (81102) data from the *Daily Summary Data* section and *Particulates* subsection. Filter-based data uses FRM and FEM monitors, which are EPA approved, and are more accurate than continuous monitors. However, measurements are less frequent, recording daily averages every 3 to 6 days, and the data is updated on the website twice a year. PM data starts from January 1, 2015 and when updated, includes data up to the day before the update.

b. Meteorological Data

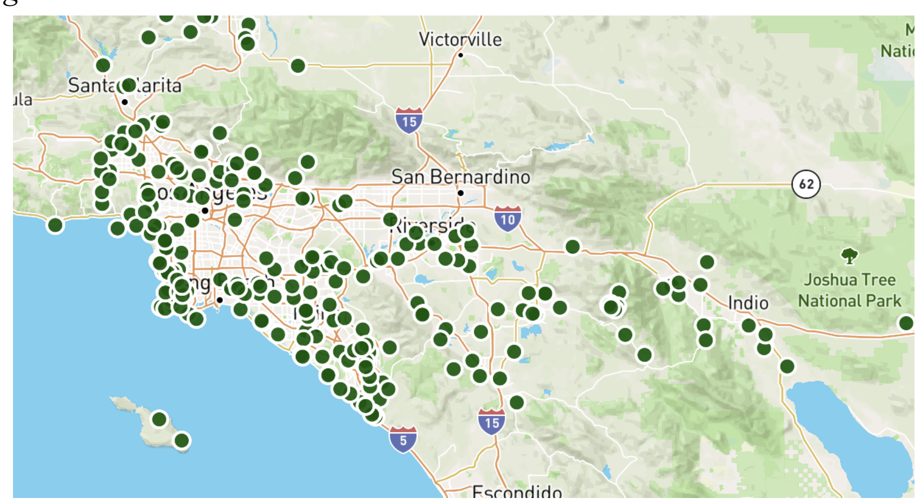


Figure 4. Map of Stations for Precipitation data from Synoptic Data

To observe and analyze what can possibly affect the PM data, we decided to use meteorological data which is variables such as pressure, temperature, wind speed, and humidity that researchers can use to predict the weather. Meteorological parameters can affect the concentration of PM because air movement influences the concentration of air pollutants. As mentioned above, When the air is quiet and contaminants are unable to disperse, their concentration rises. Conversely, strong, turbulent winds remove pollutants quickly, resulting in reduced pollutant concentrations. For this project, we decided to include wind speed, wind direction and precipitation into the app because higher wind speed will increase the PM 10 values, while higher precipitation will decrease them. The map provided above shows the database where we pulled our precipitation measurements from. To collect the meteorological data, we used Synoptic data as our primary source, and South Coast AQMD provided us with various scripts and functions to read and analyze the data by Matlab and Matlab Appdesigner.

c. Satellite Data

Satellite Imagery data was taken from NASA Worldview and NOAA AerosolWatch. Six satellite products were included from NASA Worldview from three different satellites (Terra, Aqua, and Suomi NPP) and two sensors (MODIS and VIIRS). A disadvantage with NASA Worldview is that the satellites are polar orbiting, and only capture static images of aerosol measurements once a day. This means that it may not be able to capture a dust event. However, these satellite products are higher resolution, so it can be useful when it does capture a high PM event. All NOAA AerosolWatch products are included in the app. GOES-16 and GOES-17 are geostationary satellites, and can capture the dust events in one area throughout the course of a day.

d. Source Receptor Area Groups

Consulting Los Angeles geography and our client's knowledge of regional PM_{10} trends, we identified six broad regions with unique pollution characteristics. These regions, called "Source Receptor Area Groups," were devised from 38 "source receptor areas" provided to us by South Coast AQMD.

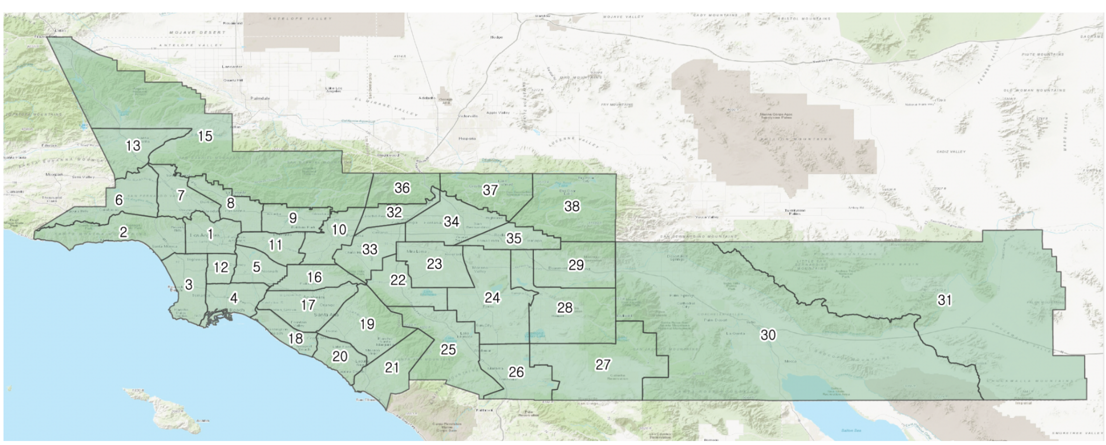


Figure 5. Shapefile of 38 "source receptor areas"

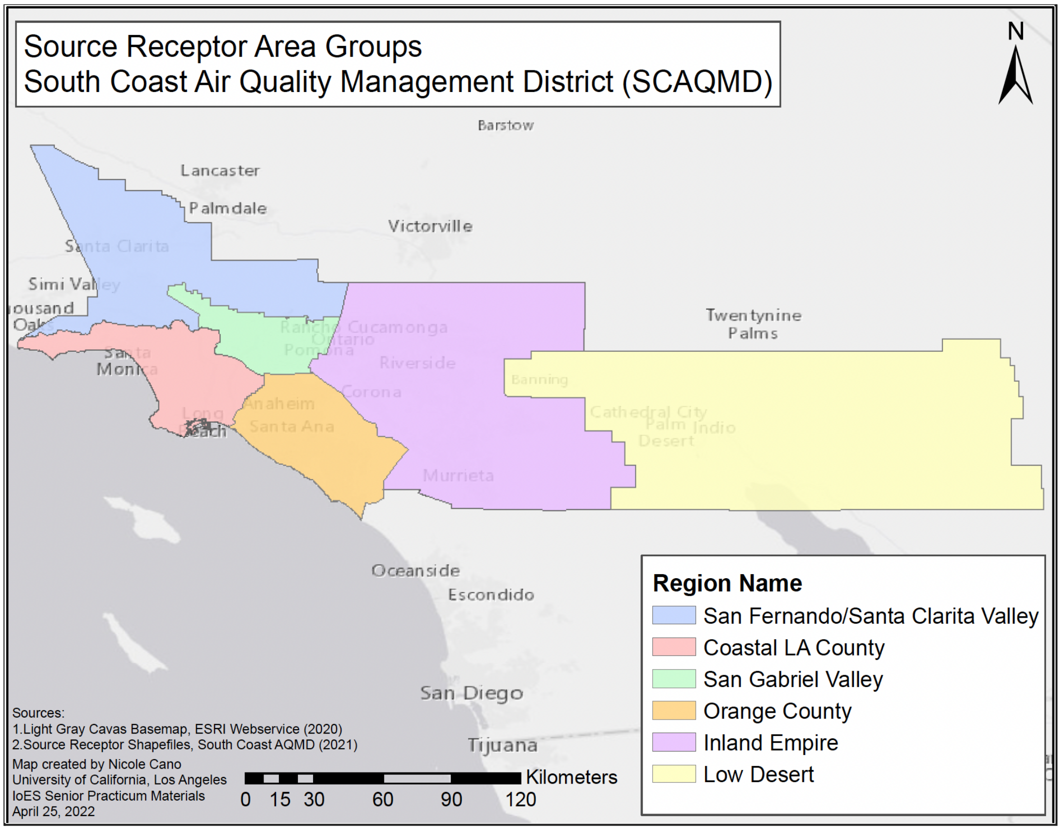


Figure 6. Source Receptor Area Groups are broad regions with unique PM10 characteristics

Source Receptor Area Groups (SRAGs) are integral to our app's functionality. First, along with date selection, they serve as a crucial basis for aggregating meteorological data. Specifically, the user's choice of primary station will populate tabs with *all* wind and precipitation values for its corresponding SRAG. Second, by orienting PM stations within a given region, SRAGs enhance the user's understanding of meteorological context. For example, if we suspect that an exceedance is caused by high winds, we can look to nearby meteorological stations to view the (wind, dust, rain) conditions for that time period. If our findings align with requirements from EPA's 2016 rule, the exceedance may qualify as an exceptional event (See Section III, 2.1, b).

e. Tab Functionality

The different datasets and general workflow were organized into seven tabs in the application. Three tabs analyze a specific parameter or a group of related parameters (PM tab, wind tab, and rainfall tab), and the rest (home tab, combined analysis tab, historical data tab, satellite data tab) help collect data and/or conduct ancillary analyses. The function of each tab is elaborated in section 6.

6. Results

6.1 Flow chart

The schematic below shows an overview of our app's basic features. It can be accessed by clicking the "Help" button in our home tab.

The home tab is also where users will make their starting selections. This, in turn, will populate each of the remaining tabs with site-specific and date-specific data. From there, most tabs offer an even narrower selection. Meteorological tabs (wind and rainfall) allow the user to pick specific stations to analyze, while PM, Combined Analysis, and Historical tabs generate data displays by the user's choice of PM-indicator(s).

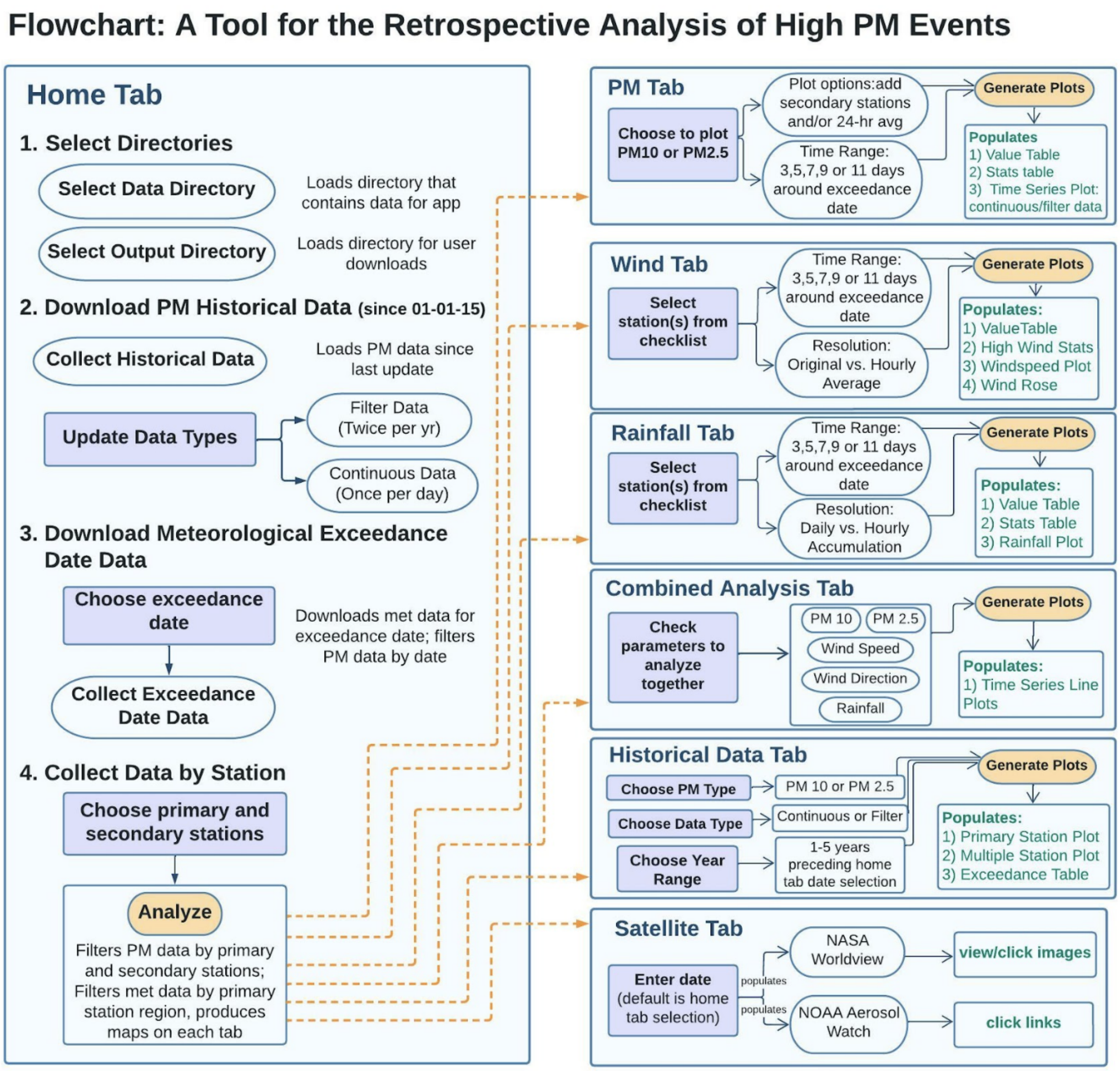


Figure 7. Flowchart of app functionality

6.2 App Walk-through

a. Demonstration Dates: April 9, 2019 and December 24, 2021

To demonstrate a full range of capabilities, this report will guide readers through the app on two specific dates. The majority of the demonstration will be based on April 9, 2019– a date on which South Coast AQMD confirmed and documented an exceptional event due to high winds. However, since there was no precipitation on this day, the rainfall tab will refer to December 24, 2021.

Throughout the demonstration, *all* tabs will display data from the same stations. As per our client's recommendation, we made the following selections:

Primary Station: Los Angeles- North Main Street (12)

Secondary Stations: LAX Hastings (8) and Long Beach Hudson (10)

These stations reside within the Coastal LA County area group, which was highly impacted by high winds on the day of the exceptional event. The area also received substantial rainfall on our second test date, December 24, 2021.

b. Home

The home tab is the first tab that the user should navigate. Its chief purpose is to select the exceedance date and stations of interest, and collect and filter data based on those selections.

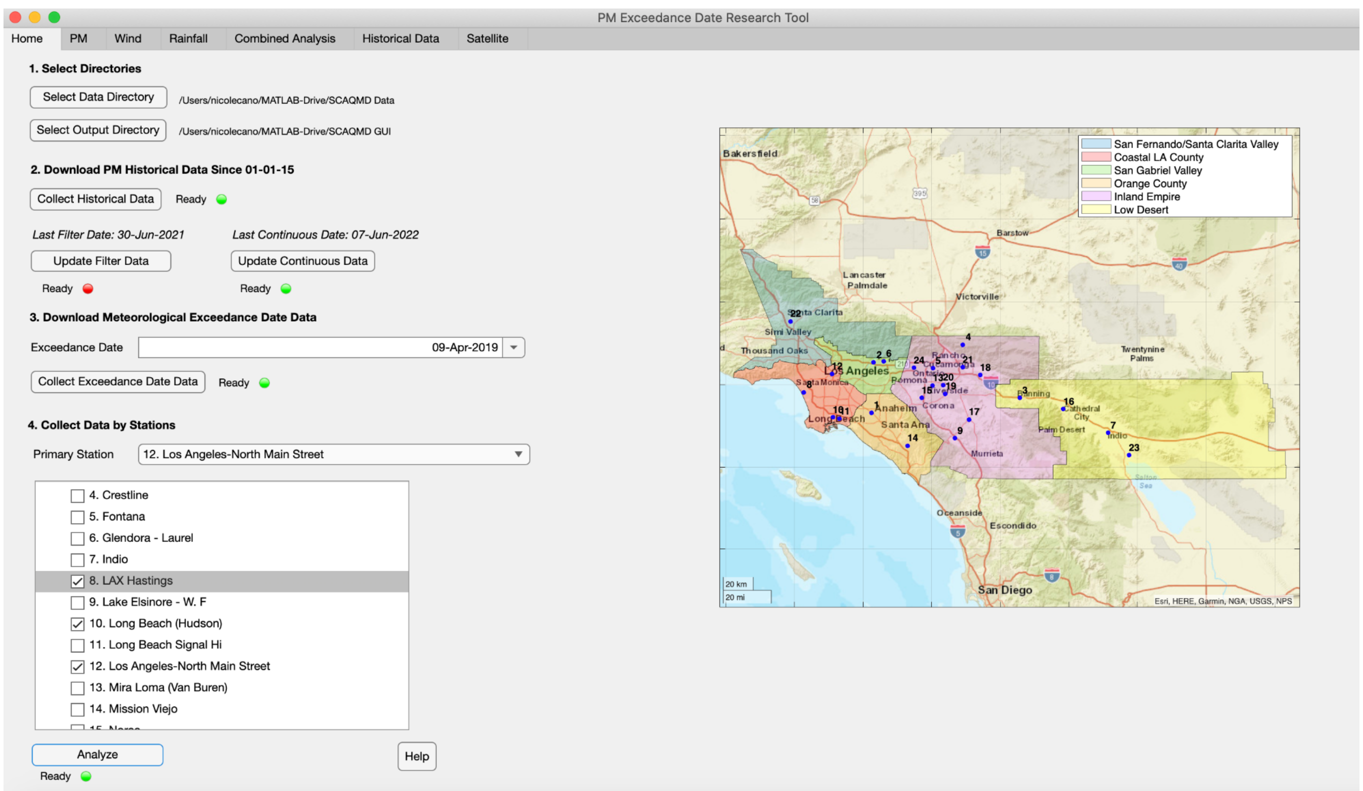


Figure 8. Home tab overview

The topmost section allows the user to first choose two directories: the folder in which all of the existing data is stored, and the one in which they want to save their data outputs from the other tabs. Once a directory is selected, the file name will appear as static text next to the corresponding button. The same folder can be chosen for the two directories (Figure 9).

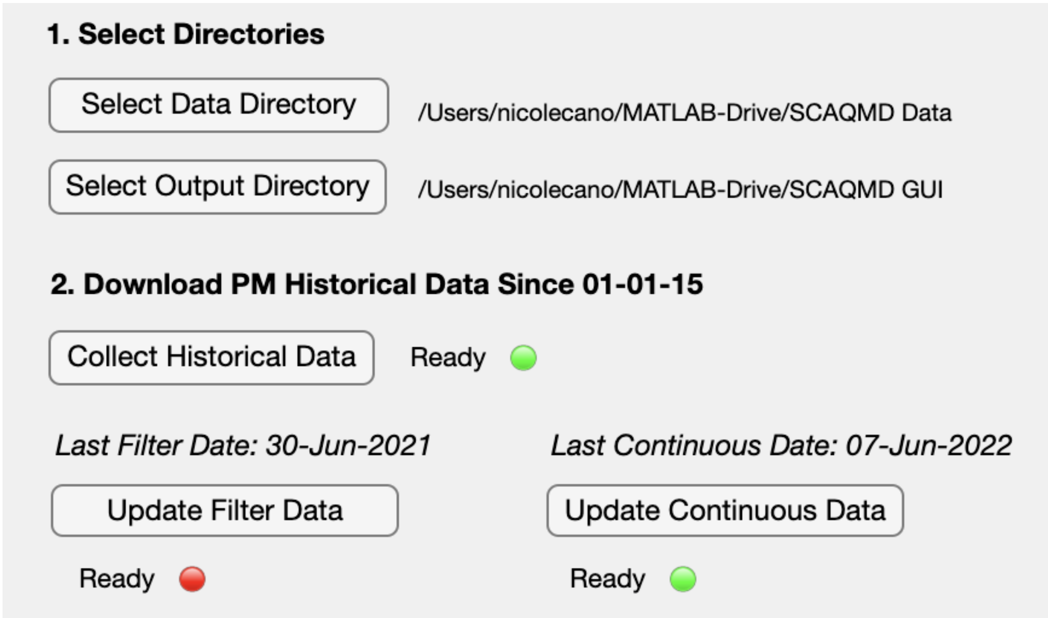


Figure 9. Home tab directory, PM updating features

Next, the user downloads historical PM10 and PM2.5 data since January 1, 2015. First, the user should click on the "Collect Historical Data" button to load the historical filter and continuous PM data. Once this operation is finished, the lamp next to this button will turn green. A map of all of the PM stations and source receptor areas will also appear on the right hand side of the tab for the user's reference. The user can then choose to update filter and/or continuous PM data; the labels above the update data buttons inform the user of the latest updates. The lamps next to these two buttons will also turn green once their operations are completed.

Next, the user can download the meteorological data. The user must first select the date in which they know an exceedance has occurred. The date must be no earlier than January 1, 2015 and no later than the day before the current date; otherwise, an error message will appear. The proceeding button downloads online meteorological data for the entire basin for the chosen date; the button lamp turns green once this action is completed.

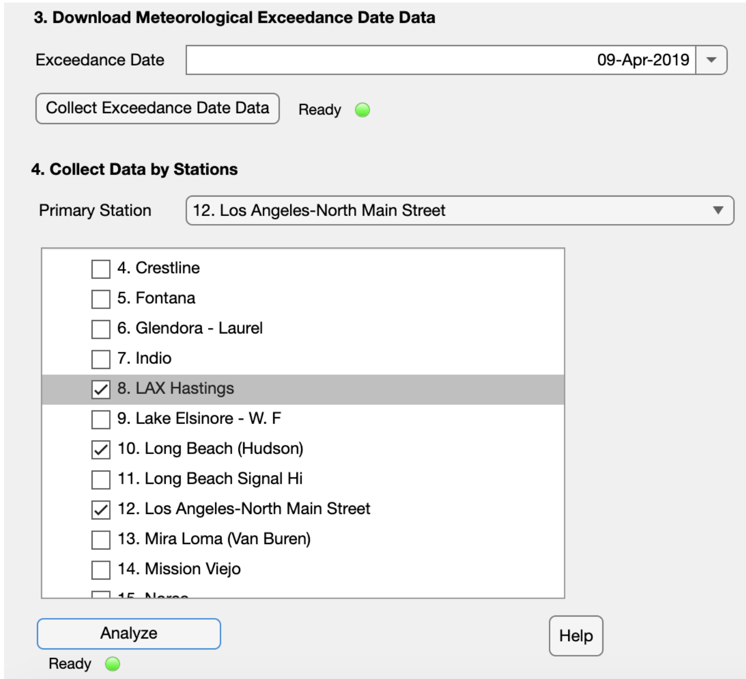


Figure 10. Home tab directory, exceedance date and station selection

When the exceedance date is chosen, the satellite tab will automatically display images from each of the satellite products for the chosen date.

The user can then select the stations that they wish to focus on (Figure 10). The user must select a primary station, the station where the exceedance occurred. If there are any additional stations that the user wishes to compare to the primary station, then the user can check those stations in the list of secondary stations. The list of primary and secondary stations are the same.

Once all of the options have been selected, the user can click the analyze button, which mainly filters PM and meteorological data by date and stations. For the date, the analyze button filters data by a time range of 11 days – 5 days before, on the day of, and 5 days after the exceedance date – as the default since 11 days is the largest time range to visualize the data for most of the other tabs. As for locations, the button filters the PM data by primary and any secondary stations chosen, but meteorological data is filtered by all of the meteorological stations included in the source receptor area that the primary station is in. A progress bar will pop up showing the progress of the filtering of wind data specifically.

Once data has been filtered, certain parts of other tabs will be populated. For the PM tab, a map displaying the selected primary and secondary stations and the source receptor areas they are in will pop up in the bottom right corner. For the wind tab, a list of all of the meteorological stations within the source receptor area that the primary station is in will be populated in the top left corner. Additionally, a map of the wind stations within the source receptor area of interest and the source receptor area will be displayed to the right of the list of meteorological stations. The list of stations and map will appear for the rainfall tab as well. The same lists of wind and rainfall stations will also be populated in the combined analysis tab.Once all of these operations have been completed, the lamp next to the button will turn green.

c. *PM*

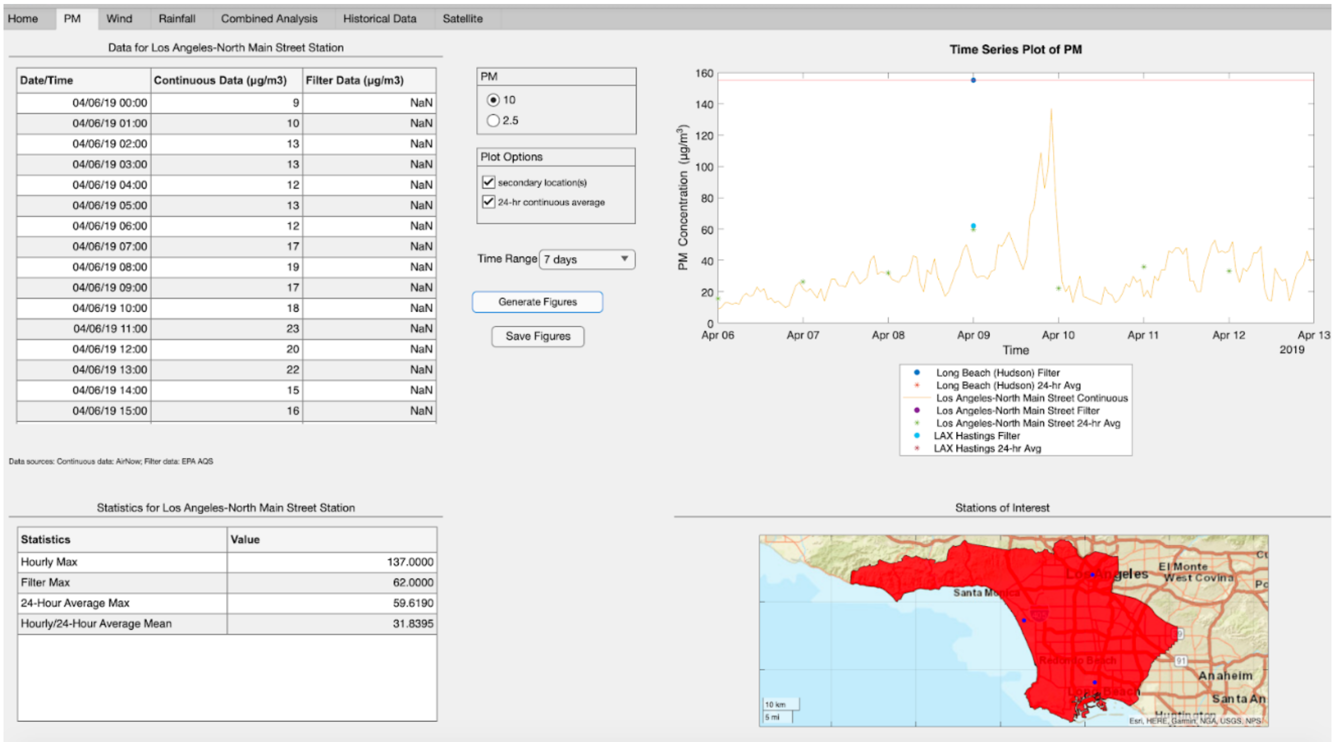


Figure 11. PM tab overview

The PM tab allows the user to analyze PM10 and PM2.5 data. Firstly, at a minimum, the user must select which of the two parameters to analyze and the time range over which the data should be analyzed. The user can choose whether to analyze PM10 or PM2.5 data using the PM radio button group. For time range, the user has the option to choose 3, 5, 7, 9, and 11 days. If the user chooses 3 days, then data from one day before, on the day of, and after the exceedance date will be displayed for a total of three days; if 5 days, then data from two days before, on the day of, and two days after the exceedance date will be displayed for a total of five days. The same pattern is applied for time ranges of 7, 9, and 11 days, the latter in which data from five days before, on the day of, and five days after the exceedance date will be displayed for a total of 11 days. Once a parameter and time range is chosen, the user should then click the “Generate Figures” button. The tables and time series plot will then be populated.

There are two tables on this tab: one displaying continuous and filter data for the chosen parameter and time range, and one displaying various statistics. Both of these tables only show data for the primary station.

The time series plot displays continuous and filter data for only the primary station by default. The user can also choose to plot secondary stations by checking the checkbox in the “Plot Options” group. The other checkbox in the “Plot Options" group allows the user to plot the

24-hour average of continuous data for each station. The x-axis spans the selected time range and the y-axis the range of PM values. Continuous data is shown as a line, filter data is shown as a scatter plot, and 24-hour continuous averages is shown as a scatter plot with asterisks marking each point. If any data point surpasses 155 ug/m^3, a red horizontal line at y=155 will appear on the plot. Each station and the types of data plotted (continuous, filter, 24-hour continuous average) is plotted with their own color and labeled separately in the legend.

Each time the user changes an option, the user must click on the "Generate Figures" button again to apply those changes to the tables and plot.

Different stations have only certain datasets. Some may only have PM10 data instead of both PM10 and PM2.5 data. Some may also not have any continuous data or filter data. In cases where a certain dataset is not available for a given station, tables will not be filled, and the corresponding data points will not be plotted on the time series plot. For instance, in this test case, continuous data is plotted only for Los Angeles - North Main Street station, which means that continuous data exists only for this station and not any of the other selected stations (Figure 11). Finally, the user can save the current figures from this tab to the designated output folder to include in their reports.

d. Wind (Speed and Direction)

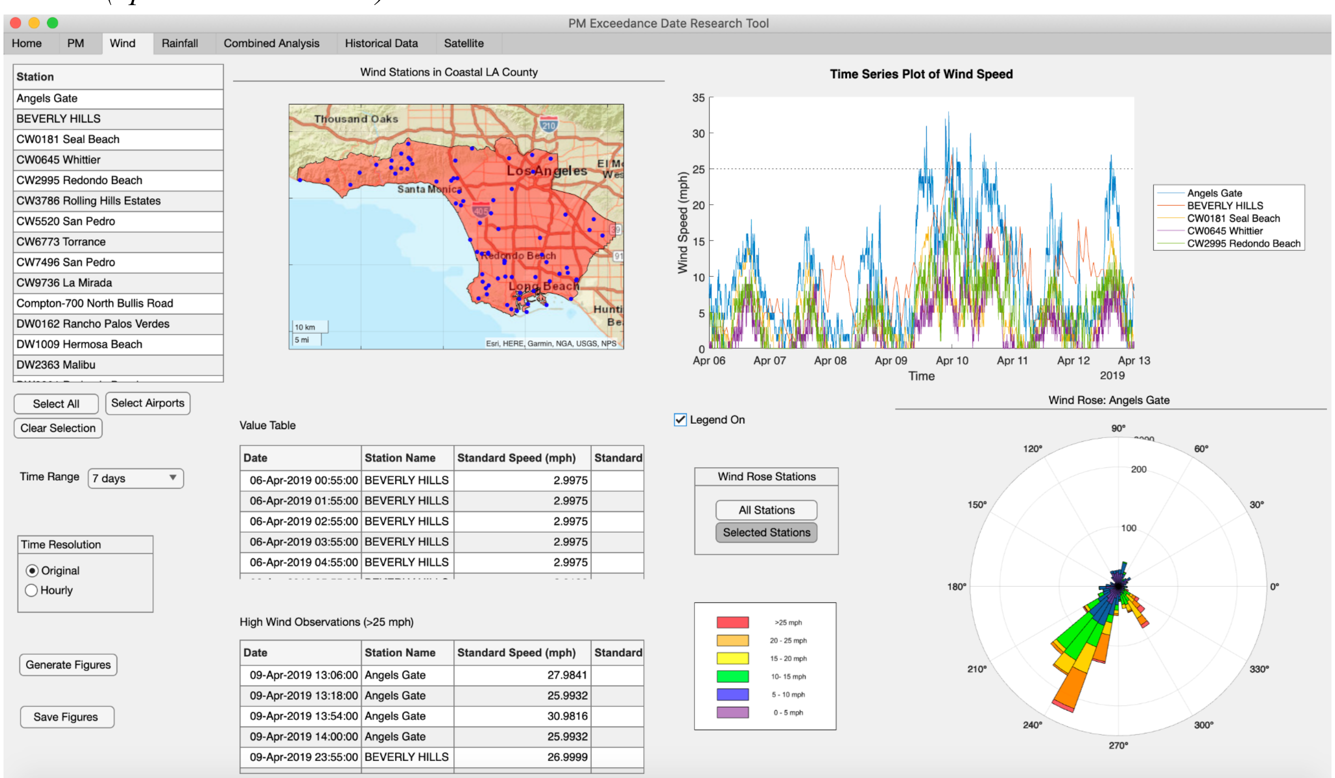


Figure 12. Wind tab overview

After the user makes their home tab selections, they are free to navigate to any of the following six tabs, including the wind tab (Figure 12). As previously mentioned, this tab populates according to the user's selection of date and primary station. Once here, they should begin at the station selector, located in the top left corner of the tab (Figure 13).

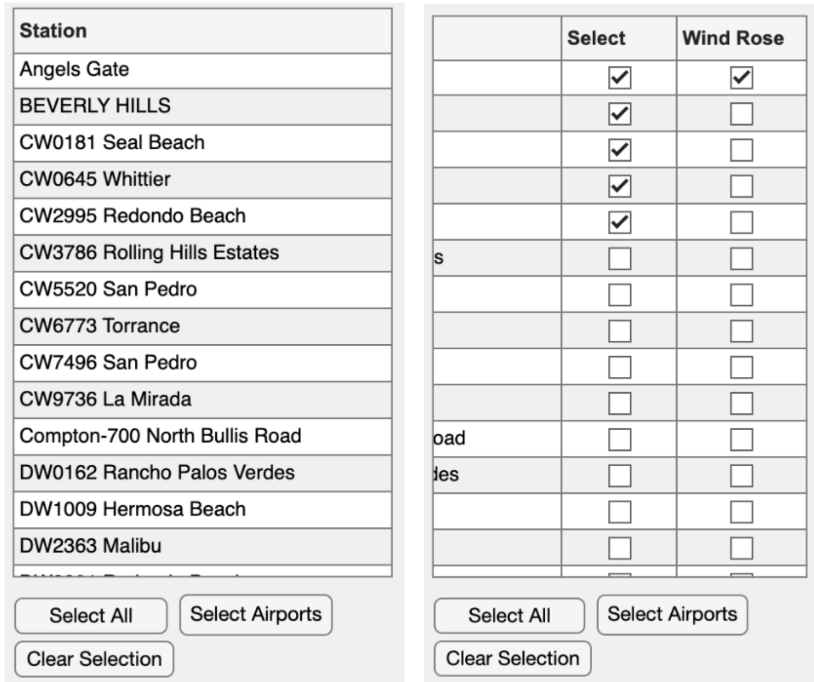
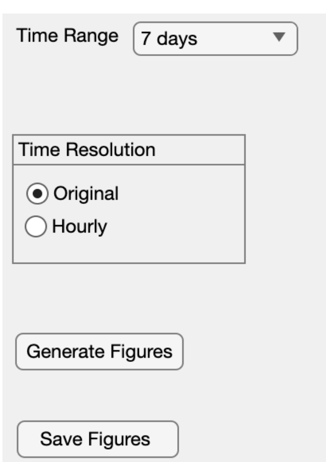


Figure 13. Wind tab station selector with two columns

Scrolling over this component reveals two additional columns: (1) a selector which allocates data for the time series plot, value table, and high wind observations, and (2) a selector which allocates data for the wind rose. Note that the "select all", "select airports", and "clear selection" buttons only work for the first column of data. This is because the "wind rose" column has a recommended limit of one selected station; depicting a wind rose with multiple stations can produce misleading results. To address this, we have integrated a pop-up warning if the user chooses more than one station from the wind rose selector column. As you can see, we chose to analyze 5 stations from the general selection column, and 1 station from the wind rose column.



As shown in Figure 14, the user must choose a time range (3, 5, 7, 9, or 11 days) as well as a time resolution. They can either pick the original data resolution– ranging from values occurring every 5 minutes to once per hour– or an hourly standard data resolution. Hourly values were aggregated using the groupsummary() function in MATLAB AppDesigner.

Figure 14. More selections

At this point, the user may press the "Generate Figures" button to populate all displays. The map of the region, however, does not respond to this callback. Rather, it is populated from the home tab using the "Analyze" button. Blue points on the map show the geographic locations of each station. After figures are generated, the user can press "Save Figures" to store tables, maps, and plots into the output folder they specified on the Home Tab.

Value Table

Date	Station Name	Standard Speed (mph)	Standard Direction
06-Apr-2019 00:55:00	BEVERLY HILLS	2.9975	168
06-Apr-2019 01:55:00	BEVERLY HILLS	2.9975	179
06-Apr-2019 02:55:00	BEVERLY HILLS	2.9975	189
06-Apr-2019 03:55:00	BEVERLY HILLS	2.9975	344
06-Apr-2019 04:55:00	BEVERLY HILLS	2.9975	29

Figure 15. The value table shows each observation's date, station, standard wind speed, and standard direction. When the hourly resolution is chosen,"standard" values are labeled "resultant" instead.

The value table displays raw data according to the user's selection of time range and resolution. Each observation comes with its date, station, standard wind speed (in mph), and its standard direction (in degrees). When data is displayed hourly (as opposed to its original resolution), speed and direction columns will be labeled "resultant." See Figure 15 above.

High Wind Observations (>25 mph)

Date	Station Name	Standard Speed (mph)	Standard Direction
09-Apr-2019 13:18:00	Angels Gate	25.9932	246
09-Apr-2019 13:54:00	Angels Gate	30.9816	242
09-Apr-2019 14:00:00	Angels Gate	25.9932	241
09-Apr-2019 23:55:00	BEVERLY HILLS	26.9999	326
09-Apr-2019 21:24:00	Angels Gate	31.9882	321

Figure 16. Statistics table displaying observations with a wind speed greater than 25 mph

According to EPA's 2016 rule, events involving windblown dust may be considered exceptional if they surpass the threshold of 25mph. To address this, we included a table that isolates such observations. As you can see in Figure 16, the Angels Gate and Beverly Hills stations recorded high wind speeds on April 9. This contributes evidence to the event's distinction as "exceptional."

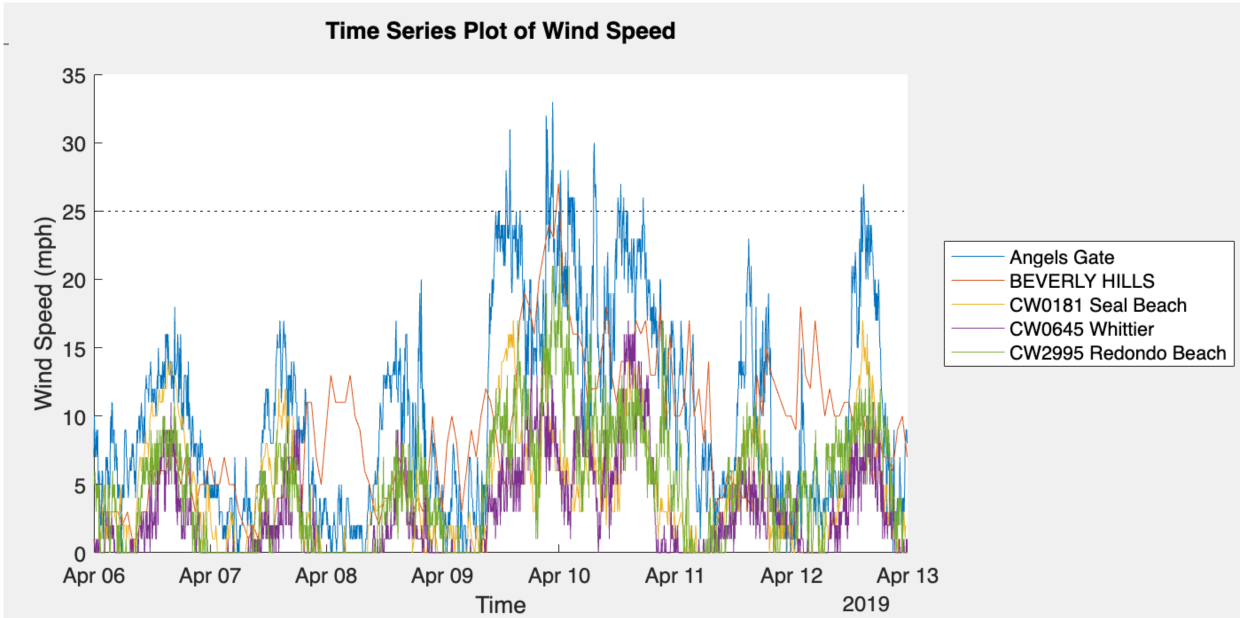


Figure 17. Time series plot with multiple exceedances of the high wind threshold

High wind observations can also be visualized through the time series plot shown in Figure 17. On the day of the PM exceedance (April 9), the same stations listed on the statistics table peak over the 25 mph threshold line. Station names can be toggled on and off using the "Legend On" checkbox located beneath this plot.

Figure 18. Wind rose legend

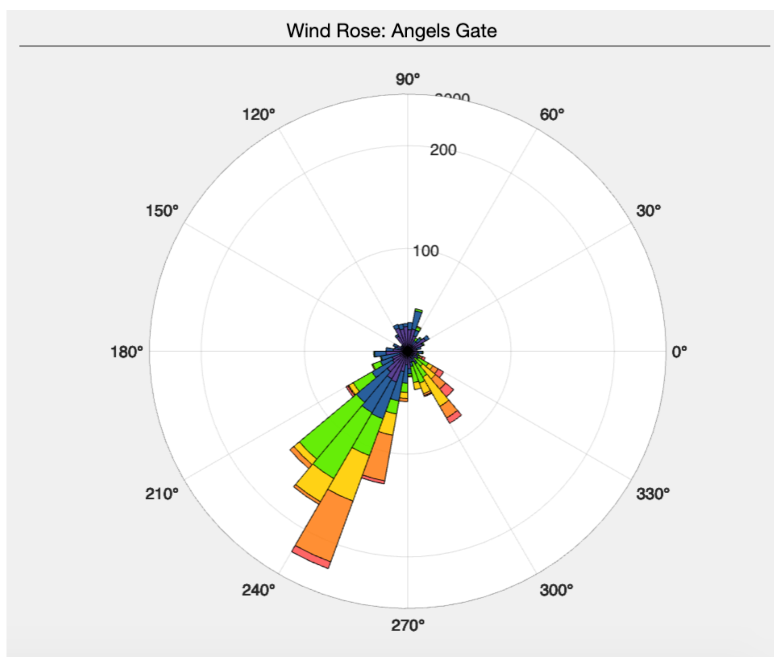


Figure 19. The wind rose displays the origin of gusts relative to the chosen meteorological station

Unlike previous features, the wind rose should only display data from one station. To accomplish this, users will utilize the “wind rose” column in the station selector, choosing one meteorological station to analyze. After selecting time range/resolution and pressing “Generate Figures” the wind rose will populate accordingly. As shown in Figure 19, our selection (Angels Gate) received its strongest winds from a direction of 250 degrees. As such, about 240 observations (see gridlines) originated from the Southwest direction. Furthermore, since a few of these observations are pictured in red, we know they surpassed the high wind threshold (Figure 18). This too provides evidence that the PM exceedance was exceptional.

e. Precipitation

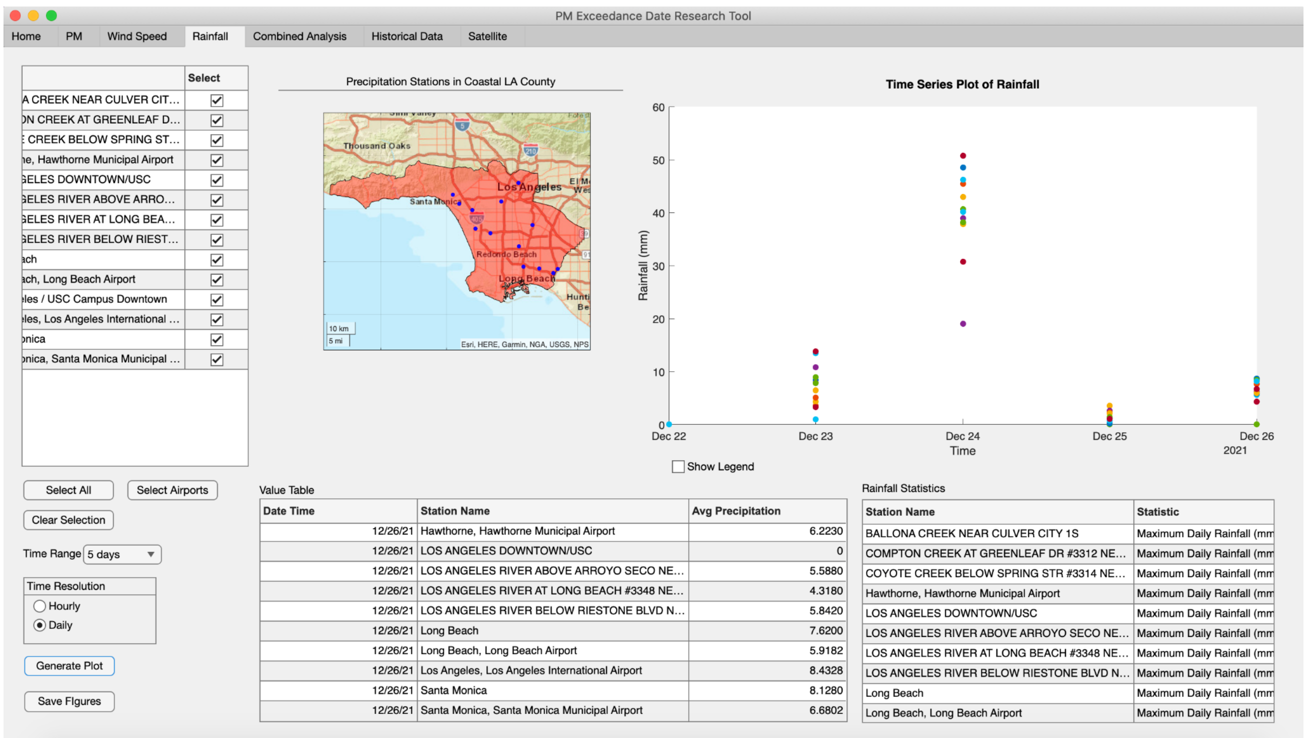


Figure 20. Overview of rainfall tab

The precipitation tab utilized the same synoptic data sources as the wind tab, and populates according to the user’s selection of date and primary station. On the upper left corner, just like the wind speed tab, users can select the station(s) for which they want to generate plots and tables. Buttons like “select all”, “select airports” and “clear selection” are also provided so users can easily select their stations of interest.

From under the left corner, users can select the time range (either 3, 5 ,7, 9 or 11 days) and the time resolution (hourly or daily). Daily data values (shown above in Figure 20) were aggregated by adding all maximum hourly data for 1 day. As for the hourly time resolution, we used MATLAB’s groupsummary function to separate 24-hour accumulation values. Specifically, we chose the maximum value of each hour to plot data.

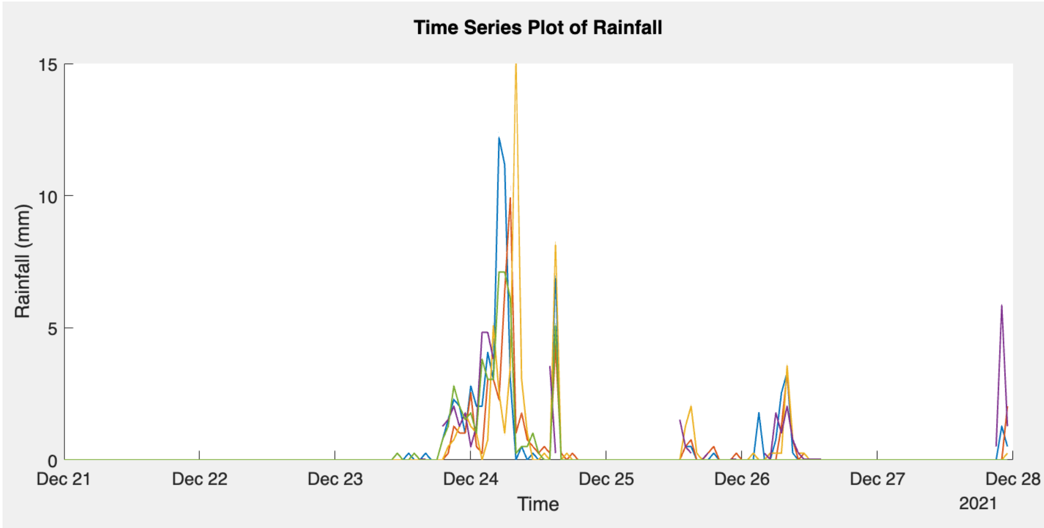


Figure 21. Time series plot set to hourly resolution

The user now can press the “Generate Plot” button to populate the plot and graph they want. Just like the wind tab, the map of SRAG does not respond to this callback. Blue points from the map represent the geographic locations of each station. Users can either toggle the legends on or off by selecting the “Show Legend" field.

When figures are populated, they depict not only the graphical data of rainfall, but also other tabular rainfall data. The value table (Figure 22) provides the average rainfall by station while the statistics table provides the maximum rainfall by station (Figure 23). Users are also able to save tables, maps and plots they generate by clicking the “Save Figures" button. This saved figure will be under the output folder user specified on the Home Tab.

Value Table

Date Time	Station Name	Avg Precipitation
12/23/21	Hawthorne, Hawthorne Municipal Airport	7.9248
12/23/21	LOS ANGELES DOWNTOWN/USC	8.8900
12/24/21	BALLONA CREEK NEAR CULVER CITY 1S	48.5140
12/24/21	COMPTON CREEK AT GREENLEAF DR #3312 NE…	37.8460
12/24/21	COYOTE CREEK BELOW SPRING STR #3314 NE…	42.9260
12/24/21	Hawthorne, Hawthorne Municipal Airport	19.0500
12/24/21	LOS ANGELES DOWNTOWN/USC	40.6400
12/25/21	BALLONA CREEK NEAR CULVER CITY 1S	1.2700
12/25/21	COMPTON CREEK AT GREENLEAF DR #3312 NE…	2.2860
12/25/21	COYOTE CREEK BELOW SPRING STR #3314 NE…	3.5560
12/25/21	Hawthorne, Hawthorne Municipal Airport	2.6162
12/25/21	LOS ANGELES DOWNTOWN/USC	0

Figure 22. Value table with average daily precipitation. If the user chooses hourly resolution, averages will populate accordingly.

Rainfall Statistics

	Statistic	Value
K NEAR CULVER CITY 1S	Maximum Daily Rainfall (mm)	48.5140
EK AT GREENLEAF DR #3312 NE…	Maximum Daily Rainfall (mm)	37.8460
(BELOW SPRING STR #3314 NE…	Maximum Daily Rainfall (mm)	42.9260
horne Municipal Airport	Maximum Daily Rainfall (mm)	19.0500
)OWNTOWN/USC	Maximum Daily Rainfall (mm)	40.6400
K NEAR CULVER CITY 1S	Maximum Hourly Rainfall (mm)	12.1920
EK AT GREENLEAF DR #3312 NE…	Maximum Hourly Rainfall (mm)	9.9060
(BELOW SPRING STR #3314 NE…	Maximum Hourly Rainfall (mm)	14.9860
horne Municipal Airport	Maximum Hourly Rainfall (mm)	5.8420
)OWNTOWN/USC	Maximum Hourly Rainfall (mm)	7.1120
)OWNTOWN/USC	Maximum Hourly Rainfall (mm)	7.1120

Figure 23. Statistics table with maximum daily rainfall values. If the user chooses hourly resolution, maximums will populate accordingly

f. Combined Analysis

Figure 24. Combined Analysis tab overview

In the combined analysis tab, the user is able to compare and analyze up to five parameters: PM10, PM2.5, Wind Speed, Wind Direction, and Rainfall. First, the user must select what wind and precipitation stations they want to view. They also have the option to select only airport stations or all stations. For wind speed and wind direction, the wind resolution can be displayed in its original setting or by the hour, whereas for rain, the user has the option to display precipitation data in an hourly or daily resolution. Once the stations are chosen for the wind and rainfall data, the user has the option to display PM secondary stations and choose a time range between 3 - 11 days. Once the user clicks on the 'Generate Plots' button, all the plots will be displayed. The PM10 and 2.5 plots will display the data according to the PM tab, the primary and secondary stations and the exceedance date chosen on the home tab. The user also has the option to show the legends for each plot, or they choose to not have them be displayed. This allows the user to compare the plots vertically according to the date and time in each plots' x-axis. See Figure 26 below for a closer view. Finally, the user can save the figures from this tab to include in their reports.

Figure 25. Comparative Analysis of PM, wind speed, wind direction, and rainfall parameters

g. Historical

The Historical tab allows users to compare the PM data from the chosen date with data from previous years.

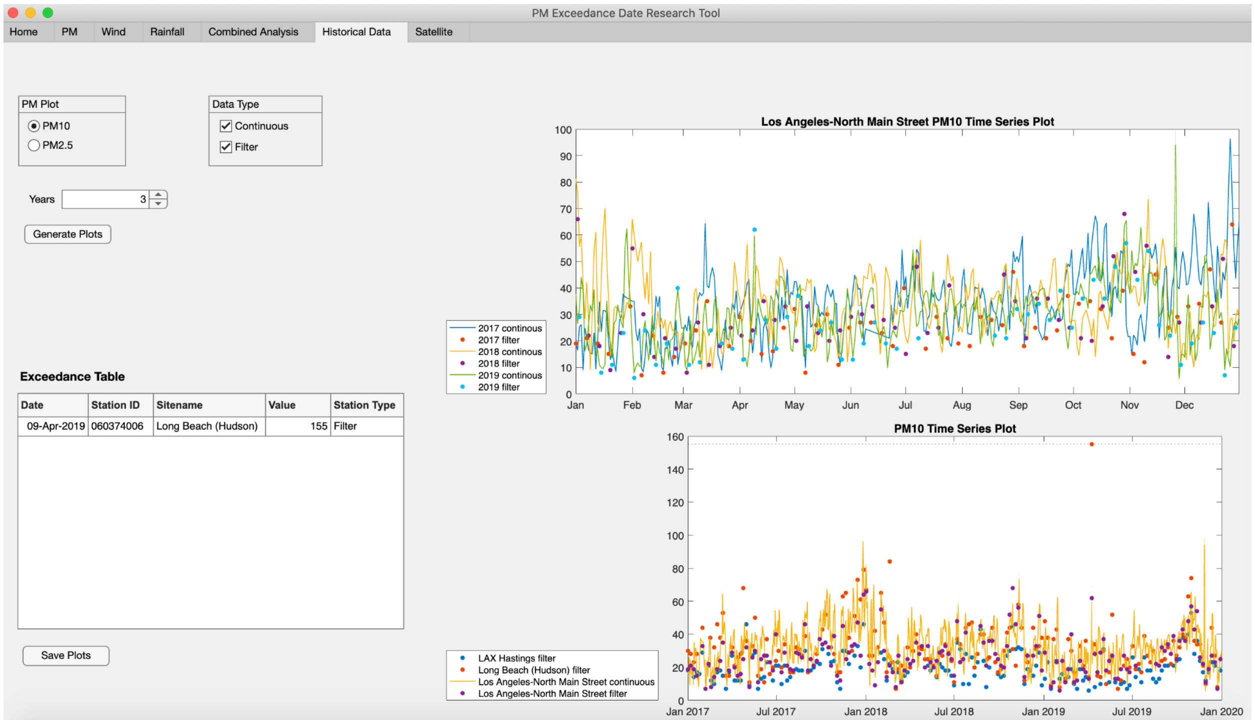


Figure 26. Historical Data tab overview

Using the PM Plot radio button group, the user can choose to look at either PM10 or PM2.5 data. The Data Type panel allows the user to choose continuous and/or filter data. The user can then choose how many years of historical data to look at. The user can look at up to five years of data, including the year of the exceedance date.

The plot on the top right shows the historical data for the chosen primary station. The x-axis spans one year, and each line is a different year. This allows the user to easily visualize and compare the historical PM levels at the primary station at a given time in the year.

The plot on the bottom right shows the historical data from the chosen primary and secondary stations. The x-axis spans the entire chosen time range and each line represents a different station. This allows the user to compare PM10 levels between stations and at different years.

The exceedance table on the left displays the date, location, and PM concentration of any measurements that exceed the 155 μg/m^3 threshold.

h. Satellite

The Satellite tab allows users to look at satellite imagery depicting aerosol optical depth for the chosen exceedance date.

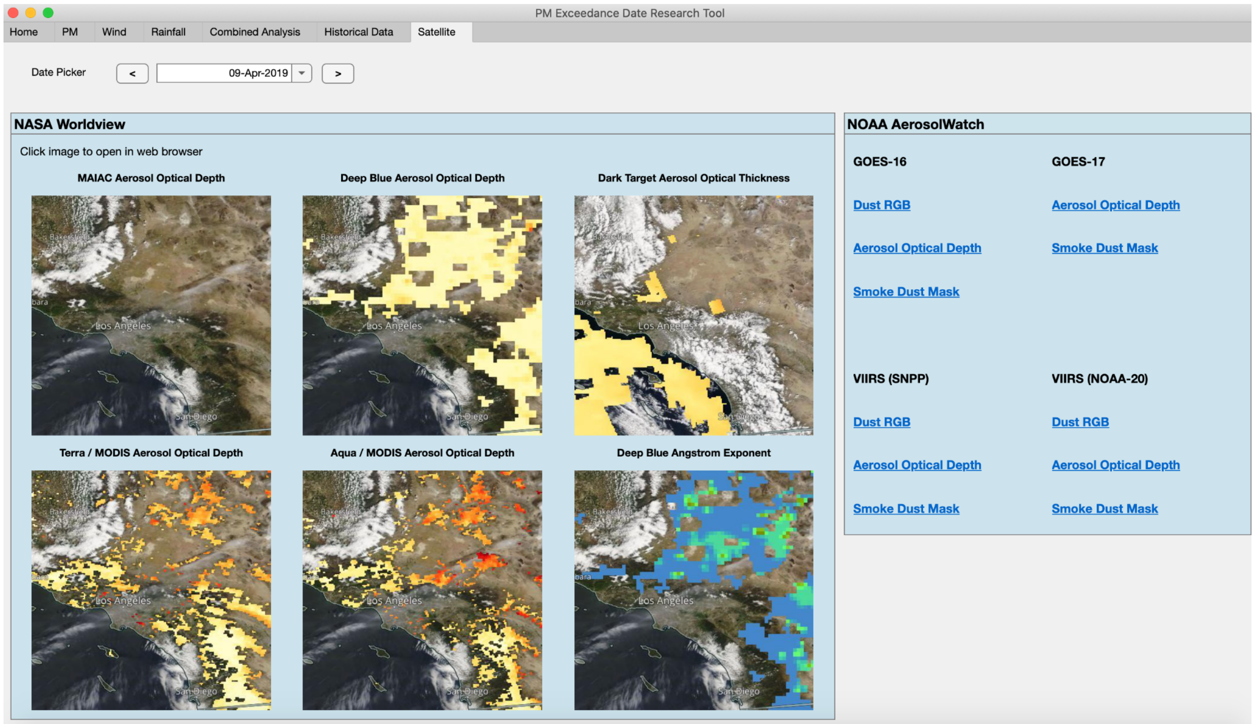


Figure 27. Satellite Tab Overview

The default date is the same as the chosen exceedance date. The user can choose a different date from the date dropdown, or move one day forward or backwards using the arrow buttons. The NASA Worldview panel displays images from 6 different satellite products. Clicking on the image will take the user to the NASA Worldview site. The image and links update when the date is changed. The NOAA AerosolWatch panel displays hyperlinks that will take the user to the AerosolWatch site. The user can modify the settings and explore other satellite products offered by NASA Worldview and NOAA AerosolWatch when opening the links in the browser.

7. Discussion

7.1 Research Reflections

The datasets that make a compelling case for exceptional events consist of PM measurements from continuous monitors that measure hourly data as well as filter-based monitors that measure every 3 to 6 days. Other datasets include meteorological data such as wind speed, wind direction, and precipitation. These parameters are important to consider since they influence PM10 levels. For example, if wind speeds reach higher than 25 mph, the exceedance may be considered an exceptional event because that’s when natural dust (rather than loosened dust from human activity) is entrained. On the other hand, precipitation decreases PM10 concentrations because the PM particles fall with the rain as it falls to the ground, reducing the concentration of PM in the atmosphere. Lastly, satellite imagery from NASA Worldview and NOAA Aerosol Watch was collected in order to depict aerosol optical depth. This allows the user to analyze and have further insight into dust events that may be taking place within the region.

Matlab's app designer can help create an app that displays plots and tables. As seen in the Home, PM, Wind Speed, Rainfall, Combined Analysis, and the Historical Data tabs, there are features like buttons, radio buttons, check boxes, dropdown lists, plots and tables that allow the user to interact with the app. For example, the buttons in the app are used to collect specific data as well as display or generate plots and tables on each tab. The radio buttons gives the user the option to choose between one of two options, for example, on the PM tab, the user is able to display PM10 or PM2.5 data depending on what radio button they choose. The checkboxes allow the user to choose multiple options that determine what kind of data they want displayed. For example, in the Wind Speed tab, there's a station selection table where the user can check off which stations they want data from. Dropdown lists help list down options that the user can click on as well as minimize the amount of space that the list can take. Finally, all of these features are used to display specific data on plots and tables which allows the user to visualize the data and give further analysis.

Through our routine meetings, air quality experts at South Coast AQMD emphasized the importance of design flexibility. To achieve this, we integrated several selection features that allow our client a multifaceted data view. For instance, the PM and Historical tabs allow users to select plotting options—such as PM pollutant type (10 or 2.5), secondary stations, a 24-hour continuous average, and data types (continuous or filter). This gives our client the opportunity to disambiguate variables through the depiction of different aspects on a single graph. Likewise, almost all tabs contain a date range, which can shorten or lengthen the data window accordingly. Time resolutions (on meteorological and combined tabs) also work to provide the user a more granular or broader view for analysis. Finally, MATLAB AppDesigner is inherently flexible. In the case of changing policy, preferences, or data availability, the client may adapt written features within the coding script.

7.2 Limitations

Although we are pleased with the app we have created and presented to South Coast AQMD, there are still potential changes that could be made to improve the functionality of the app. With more time, we were hoping to integrate the following: (1) change the map datatips to show station names, (2) streamline wind rose plotting so it's more user-intuitive, and (3) display stations that exceed 25 mph in a different point color on the wind map. South Coast AQMD assured us that these were very minimal changes that they could help integrate. Overall, our client was very happy with our end product.

7.4 Intended Uses

Our product will be used by the South Coast AQMD team to help identify potential causes of PM10 exceedance events that occur in the domain, reallocate efforts towards regulating exceedance events that actually matter, and support measures that mitigate public exposure to all exceedance events.

7.5 Acknowledgements

A special thank you to our advisor Dr. Pablo Saide for providing support throughout our project and for giving us further coding insight in every meeting. We would also like to thank Scott Epstein, Xiang Li, Nico Schulte and the rest of South Coast AQMD's team for providing us with resources as well as keeping communication with us throughout the course of this project.

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9. Appendix

Table 1. List of data sources included in the app.

Data	Source/Description	URL
Source Receptor Areas	South Coast AQMD 38-shapefile map	https://data-scaqmd-online.opendata.arcgis.com/maps/814d6e7a791044dabcb3d0d4b8af4df9/explore?location=34.179950%2C-117.287900%2C8.88
Hourly PM Data	AirNow Hourly PM data from continuous monitors; updates hourly	http://files.airnowtech.org/?prefix=airnow/
Filter PM Data	EPA Daily PM data from filter-based monitors; updated twice a year	https://aqs.epa.gov/aqsweb/airdata/download_files.html#Daily
Monitor Locations	EPA Information on all monitor locations	https://aqs.epa.gov/aqsweb/airdata/download_files.html#Meta
Wind Speed	Synoptic Data "wind_speed", pulled from stations within four counties, later filtered to jurisdiction	https://explore.synopticdata.com/metadata/map/3428,-11015,5?status=ACTIVE
Wind Direction	Synoptic Data "wind_direction", pulled from stations within four counties, later filtered to jurisdiction	https://explore.synopticdata.com/metadata/map/3428,-11015,5?status=ACTIVE
Precipitation	Synoptic Data "precip_accum_24_hour"pulled from stations within four counties, later filtered to jurisdiction	https://explore.synopticdata.com/metadata/map/3428,-11015,5?status=ACTIVE
NASA Worldview Satellite Images	NASA Worldview Daily images from polar-orbiting satellites	https://worldview.earthdata.nasa.gov/
NOAA AerosolWatch Satellite Images	NOAA AerosolWatch Images from geostationary satellites	https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/

Table 2. List of app files and functions.

File Name	File Type	Data Description
PM Data		
update_hourly_data.m	Function	Updates with most recent hourly pm10 data from AirNow → updates daily; saves table into full_pm10_data.mat file **Required file**: hourly_pm10_data.mat
update_filter_data.m	Function	Checks if there is new filter data from EPA and appends new data if there is; expected to update twice a year **Required file**: filter_pm10_data.mat
historical_hourly_data.m	Script	Created initial table of historical continuous (hourly) data; do not need to run this again
historical_filter_data.m	Script	Created initial table of historical filter data (vertcat_filters2) (3-6 days); do not need to run this again
filter_pm10_data.mat	Matfile	Contains filter_pm10_table that has existing filter data
hourly_pm10_data.mat	Matfile	Contains hourly_pm10_table that has updated hourly pm10 data
pm10_daily_avg.m	Function	Inputs historical pm10 table. Outputs table of PM10 daily averages
pm25_daily_avg.m	Function	Inputs historical pm2.5 table. Outputs table of PM2.5 daily averages
Meteorological Data		
Wind_Tables.m	Function	Collects wind speed and wind direction data for specified dates from Synoptic site Inputs start date, end date, and synoptic token. Outputs wind table with raw time resolutions and wind table with hourly time resolutions. **Required files**: download_synoptic_data_wind.m, download_synopticdata_metadata.m, standardize_data.m
Precipitation_Tables.m	Function	Collects data on precipitation (accumulated over 24 hours) from Synoptic site using specified dates Inputs start date, end date, synoptic token, and parameter. Outputs precipitation table with hourly accumulated values and precipitation table with daily accumulated values. **Required files**: download_synoptic_data_precipitation.m, download_synopticdata_metadata.m, standardize_data.m
Wind_Rose.m	Function	Inputs: wind direction array, wind speed array, app component to display on (ex: app.panel) Creates a wind rose plot; No output

Geographical Data		
region_shapefiles.mat	Matfile	Contains shapefiles of the source receptor area groups
SR_AreaGroups.m	Script	Generates map of Source receptor area groups **Required files**: region_shapefiles.mat
PrimStation_Polygons.m	Script	Adds columns to primary stations to locate them within SR Area Groups **Required files**: hist_pm_data.mat, region_shapefiles.mat
label_met_stations.m	Function	Inputs met station table. Outputs met stations table with their regions. **Required files:** Region_shapefiles.mat
get_met_region.m	Function	Inputs met station table and region shapefile. Outputs table of met regions filtered to input region
Other		
leapyear.m	Function	Inputs year, checks if year is a leap year
filter_pm_data.m	Function	Filters PM data by time range and primary and secondary stations chosen
home_mapimage8.m	Function	Cleans table of historical PM10 and 2.5 filter and continuous data, also creates matrix of unique PM stations and relevant information