2021 29th Mediterranean Conference on Control and Automation (MED)
June 22-25, 2021. Bari, Puglia, Italy

An adaptable Web GIS platform for monitoring Port air quality

George Pachoulas
Laboratory of Knowledge & Intelligent Computing
University of Ioannina
Arta, Greece
pachoulas@kic.uoi.gr

Stefanos Petsios
Laboratory of Knowledge & Intelligent Computing
University of Ioannina
Arta, Greece
stefanos@kic.uoi.gr

Evangelos D. Spyrou
Laboratory of Knowledge & Intelligent Computing
University of Ioannina
Arta, Greece
e.spyrou@uoi.gr

Chrysostomos Stylios
Laboratory of Knowledge & Intelligent Computing
University of Ioannina
Arta, Greece
stylios@uoi.gr

Abstract—In recent years, advances in IT technology affects a plethora of sectors such as environmental monitoring and management. Open source web map based Geographic Information Systems (GIS) offer a significant advantage in monitoring and representation for many environmental parameters. Here a WebGIS platform based on OpenLayers is presented that displays a set of environmental parameters using novel techniques such as schematic-color methods and 2D arrays. OpenLayers is an open source web maps development tool for WebGIS client that it is characterized by small size and powerful functionality compared with commercial WebGIS software. The data is derived from a set of environmental stations that have been placed in 2 case study areas, in the Port of Igoumenitsa (Greece). The stations transmit data using MQTT protocol that provides convenience and security in data communication. The data is displayed on the platform via a heatmap and color schemes as well as through a 2D array and it can provide both historical and future data. It is noted that the proposed platform is adaptable to making modifications and expansions such as adding new environmental variables for viewing or adding new stations and case study areas by using configuration files that requires minimal programmable skills.

Index Terms—WebGIS, OpenLayers, MQTT, Open source web map, environmental monitoring, smart cities

I. Introduction

With the continuous evolution of technology, new ways of interaction between human and the environment have been created in order to enhance the possibility of monitoring its degradation [1]. The increased accessibility to cutting edge technologies and the variety of skillset held by the average citizen generate prospects of a novel methodology for protecting and preserving the environment [2]. Human activities are characterized as the main source of climate change. Enriching human activities with technological solutions may act as a springboard to minimize environmental impacts on everyday life [3]. Towards this goal, one of the most promising, yet affordable solutions is the concept of the "Internet-of-Things" (IoT) [4]. IoT refers to a global network of machines and devices with the ability to interact with each other. At the same time, they have the ability to interact with the real world through physical objects embedded with different types of sensors [5]. IoT can have a profound impact on living when integrated with Geographic Information System (GIS), since location is such a crucial facet of IoT data. Many organizations and businesses find that a modern GIS, fed by real-time data, archive data and prediction models can be a smart powerful tool providing useful information and supporting decision making. Smart solutions are the pillars of smart city development which comprise the advanced integration of GIS and IoT together to fulfill its demand for Information and Communication Technology (ICT) based infrastructure development [6]. Further visualization and analysis are essential in order to locate and possibly recognize sources of environmental degradation [7]. This purpose serves a GIS platform which is integrated to a web interface developed specifically for this study.

In this paper, we describe a platform, which solves the problem of multiple variable mapping at the same time. The platform's main feature compared to other similar ones is the display of data in multiple ways. The platform visualizes more than five variables using schematic and color representation methods combined with a 2D Array, which offers a detailed display both in previous days and in a forecast for the next few days.

The developed platform is based on MQTT connectivity protocol. MQTT is a lightweight publish-subscribe "Internet of Things" network protocol that transports messages among devices. This protocol is ideal for establishing connections to remote locations that require a small data packet due to its low power consumption and efficient information distribution to one or more receivers.

The MQTT protocol is divided into two types of network entities: a message broker and several clients. In a MQTT network the main server is called MQTT broker and is responsible for receiving all the messages from the clients and route them to the appropriate destinations. An MQTT client is any device that runs an MQTT library and connects to an MQTT broker [8]. The reason for choosing this protocol is the ease of adding additional stations, its supports of many devices that can be easily customized to communicate using the MQTT protocol and its security in communication.

The WebGIS is developed with JavaScript pure client, OpenLayers, and invoked in the HTML document. OpenLayers is a JavaScript class library package for WebGIS client development, which is used for network access to map any kind of monitoring data such as air pollution data, wind speed and direction data etc. It provides the ability to view data on maps as well as possibilities for further expansion. The reason for choosing OpenLayers is that the system is open source, and the JavaScript language and OpenLayers library are easy and flexible to use. Moreover, it can make full use of HTML5 technology, adapting the continuous improvements of client computer performance, and reducing the pressure of server-side page processing.

The rest of this paper is organized as follows. In Section II , we introduce the related work, Section highlights the system model and underlying framework. Then in Section IV we present the basic components of the developed WebGIS as well as how it displays the available information. Finally, the discussion regarding the conclusions and prospects of the proposed framework is presented in Section V .

II. Related Work

There is a research work where an air quality monitoring system is developed based on IoT technology by using MQ135 gas sensor to sense various types of dangerous gases, Wi-Fi connection to internet and GIS to monitor all points of air pollution of a broad area [9].

Another application through the use of the MQTT protocol is the water quality monitoring system developed by Yuan et al [10]. The system receives real-time data from sensors placed underwater for storage and further processing and analysis. The results of the processed data are displayed through ArcGIS. Using a GIS map, they display the geographic location of study points to achieve the correspondence between spatial position and water quality data.

Pope et al. [11] describes a GIS-based multi-objective assessment work, which essentially takes into account environmental, social and environmental indicators. This approach assesses the O_3 and PM_{10} monitoring networks in the metropolitan area of Phoenix. In particular, the assessment includes a site-to-site comparison of every monitoring station using a number of indicators. Also, GIS-based spatial models provide information whereby the Air Quality Monitoring Networks (AQMN) are not adequate to monitoring air quality and more sites are needed. Furthermore, the assessment incorporates recommendations on the improvement of AQMNs are made in order to proceed with reconfigurations. This paper emphasizes the sustainable development approach, whereby indicators are categorised as supporting environmental, economic or social objectives. The paper also includes analyses to conclude whether minority populations were suffering from disproportionate risk from air pollution.

In [12], the authors describe the QuickDeform, which is a WebGIS platform that creates near real-time coseismic ground deformation map in less time than would be required with conventional methods. Furthermore, it visualizes them on an interactive WebGIS platform reducing both hazard evaluations and emergency responses.

Shi et al. [13] describes an approach of characteristics, behaviour as well as trends of $PM_{2.5}$ together with the correlation with a number of meteorological parameters. In addition the study provides a state-of-the-art modeling and displaying technique of $PM_{2.5\Delta z}$ vertical profiles. The concentrations of the $PM2.5$, in conjunction with the meteorological parameters were analysed in order to examine daily and seasonal variations and relations. The conclusions of this work consist of the fact that dense traffic directly as well as seasonal wind direction influences $PM_{2.5}$ concentrations. Finally, the authors provide a GIS-based 3D urban model, in order to show near-real time display. As a result, the $PM_{2.5\Delta z}$ 3D database provides decision makers and regulators with the necessary information to setup up tasks and strategies that comply with air quality standards. A web interface will be implemented as a future work.

III. System Design

Here the development of a GIS is presented, based on open-source technologies that are playing a pivotal role in the implementation of the platform. Geographic Information Systems are systems responsible for the storage, analysis and presentation of geographical and spatial data [14]. Combining data that is slightly related to each other using GIS results in the discovery of spatial patterns [15]. Geospatial data are created, shared, and stored in many different formats [16]. Open-source maps are visual mapping from GIS data with reusable information without inclusion in any control mechanism. OpenLayers is a tool for client development; It is the main choice of many users compared to other WebGIS tools in recent years.It provides many development opportunities and it has been applied in many fields such as weather, sea ship management, etc.

A. System Framework

Most Web GIS applications are based on the client-server model. The client communicates with the server

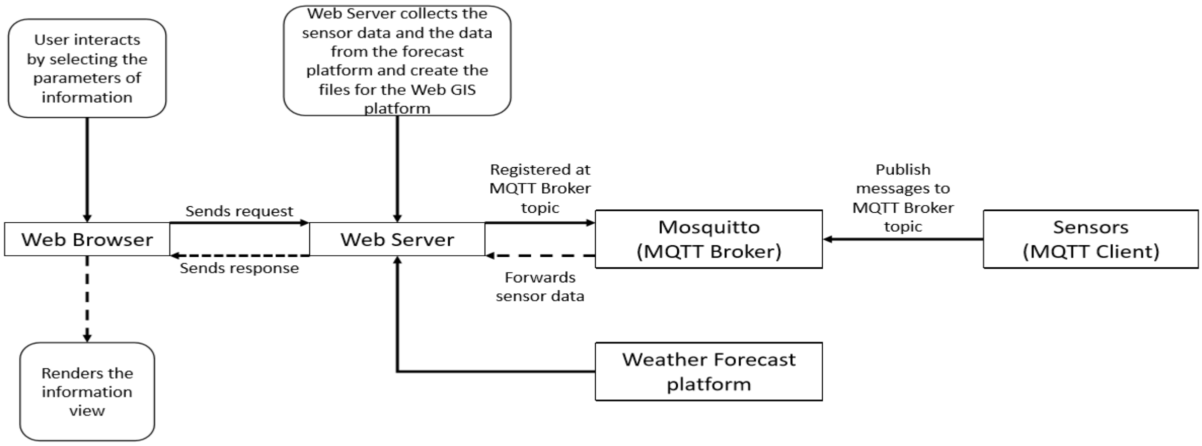

Fig. 1. Schematic diagram of WebGIS architecture components and their interactions.

through a web browser and the server responds to the client request by sending back the required information in a web page format. The presentation layer or front-end application layer contains the user interface to which the user has direct internet access and communicates with the application logic layer. The presentation layer mainly through OpenLayers map display and basic operations, environmental measurements (CO_2, NO_2, NO, O_3, etc.) are implemented by superposition of map-based function layer and map service layer and the data table under the map. The application logic layer or background logic layer consists of the MQTT broker and the Web Server. For the MQTT Broker we use the Mosquitto an open-source (EPL / EDL licensed) message broker that implements the MQTT protocol versions 5.0, 3.1.1, and 3.1. The stations (publishers) send the data to Mosquitto (MQTT broker) and it then forwards it to the Web Server (subscribers). Both the Web server and the stations are MQTT Clients and should be registered on the same topic of the broker to communicate with each other. The Web Server has its own mechanism, controls all the application's functionalities, and processes the client requests; its mechanism is based on a Nginx HTTP Server. NGINX is a open-source, HTTP server and reverse proxy. The Web Server receives the data from the broker, processes it, and saves it to be used to create the files that will be sent to the Web Browser. The data layer consists mainly of various types of map services resources, weather forecast data, environmental and ecological data from stations, etc. The basic architecture components are displayed in Fig 1.

B. System back-end features

The backend is mainly based on configuration files based on which the stations and the web GIS are configured. More specifically, these files provide information such as station coordinates, variables that will be displayed/hidden in Web GIS, the scale of measurements, etc. Using configuration files, the addition of a new station and modification of existing ones is done as well as no need to interfere with the application code.

C. System user features

The interface of the application is user-friendly as it makes access to information easy. It is based on a clickable interface in which the user can choose the monitoring station of interest to load its data to the 2D array. In addition, it can change with one click the time frame of interest, thus giving direct access to historical data. The user can also select the variables that will appear in the graphical representation of the measurements.

D. The data layer in an air quality case study

The main data source for the Web GIS platform comes from our MQTT environmental stations . The RAMP (Real-time, Affordable, Multi-Pollutant) Monitor Fig. 2 is a low-cost air quality monitoring platform that is capable of monitoring up to five gaseous chemical pollutants, temperature, humidity, particulate matter, and meteorological conditions. The RAMP station contains a power supply, control circuity, a memory card for data storage and cellular network communications capability (GSM). Additional instrumentation may be integrated via four I/O ports on the side of the unit. More specifically, the data measured by the MQTT stations we have in our possession are displayed in Table I.

The study areas are in Igoumenitsa, Greece the second busiest passenger port of Greece serving 61.73% of the maritime traffic annually. In Igoumenitsa, 3 stations have been installed at the University of Ioannina (Department of Translation and Interpretation, Igoumenitsa), in the city Hall building and near the port in such a way as to cover as much area as possible. In addition to the 3 physical stations (which are represented by a cross on the map) we have added 2 artificial stations, whose

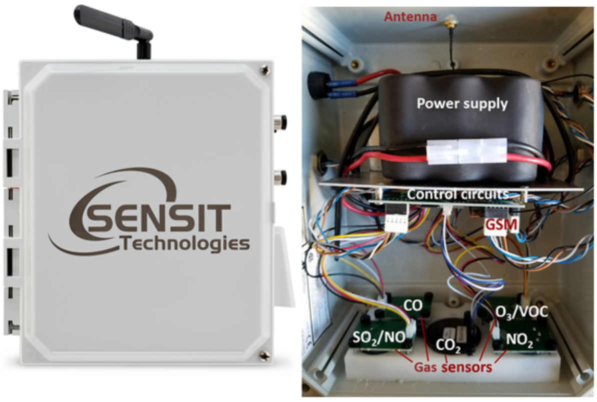

Fig. 2. External and internal configuration of the RAMP sensor station.

TABLE I
List of parameters provided by our environmental stations

Parameters	Description	Units
Date	Local Date and Time	MM/DD/YY HH:MM:SS (24H)
CO	Carbon monoxide	PPB (parts per billion)
NO	Nitric oxide	PPB (parts per billion)
NO2	Nitrogen diocide	PPB (parts per billion)
O3	Ozone monoxide	PPB (parts per billion)
T	Temperature	°C
RH	Relative Humidity	%
P	Presure	Pa (Pascal)
G	G	°(Celcius)
PM1	Particulate Matter with diameters 1mm and smaller	$\mu g/m^3$ per billion)
PM2.5	Particulate Matter with diameters 2.5mm and smaller	$\mu g/m^3$ per billion)
PM10	Particulate Matter with diameters 10mm and smaller	$\mu g/m^3$ per billion)
WD	Wind Direction	Degrees from North
WS	Wind Speed	Mph
WG	Wind Gust	Mph

measurements are obtained from the physical stations' measurements in combination with the distance between them. Measurements are made from stations every 15 seconds and then sent to the Mosquitto (MQTT broker) every 15 minutes and the broker sends them to the server. Then with an automated process these data are cleared from empty or incorrect measurements and combined in one-minute measurements to make it easier to further process them. Finally, the processed data is stored in the CSV file which will be used to create the appropriate files for both the map and the data table.

IV. Web GIS Application

A. The Web GIS Application

The Web GIS platform consists of a map (spatial data display) and a 2D data table illustrated at 3 and Fig 4.

TABLE II
List of measured parameters displayed on the WebGIS platform

n/n	Station Location Location	Map Parameters	Table Parameters
1	University of Ioannina (Igoumenitsa)	PM2.5, CO, NO, O3	CO, NO, NO2, PM2.5, O3, T, RH, P, G, PM1, PM10, WD, WS, WG
2	Town Hall of Igoumenitsa	PM2.5, CO, NO, O3	CO, NO, NO2, PM2.5, O3, T, RH, P, G, PM1, PM10, WD, WS, WG
3	Port of Igoumenitsa	PM2.5, CO, NO, O3	CO, NO, NO2, PM2.5, O3, T, RH, P, G, PM1, PM10, WD, WS, WG

The data displayed on both the map and the 2D table is described in the Table II.

The data from the stations are divided according to the time of the measurements into 6 sets of 3 hours. Then in each set the average value for each item is calculated and the appropriate files are created and sent from the webserver to the browser for depicting the data both on the map and in the table. The main file types created are KML, JSON, and CSV. For each data set 3 files are created: 2 KML files and 1 JSON for the 2D table.

B. Web GIS-map

The first component of the platform is the map, Fig 3 displays available information such as the location of the stations and the environmental data, which come from the webserver. Map elements such as heatmap and shapes, as well as the colors of the measurements, are derived from the mean of the measurements taken for each set. More specifically, the map displays the data in 2 ways using the heatmap to represent the PM2.5 element, and the schematic representation for the CO, NO, O3 elements. A heat map (or heatmap) is a graphical representation of data where values are depicted by color. The heatmap is formed by the average value of the PM2.5 element for each set and then it creates the KML file, which is illustrated at Fig 4. With the same process, the KML file for CO, NO, O3 is created. Each element is represented as a placemark in the KML file. A Placemark marks a position on the Earth's surface. The simplest Placemark includes only a Point element, which specifies the location of the Placemark. The user can specify a name and a custom icon for the Placemark, and to add other geometry elements to it. Each data file is represented as a separate layer of information on the map that is displayed at the same time. The map also contains a legend and a Layer switcher

The legend shows the correspondence of the shapes with the data of the measurements as well as the scale of the measurements for each element. For each item, the scale is divided into 5 color levels in which if the user places the mouse above any color level, the exact numerical limits of the specific level will be displayed. The Layer Switcher allows the user interface to switch

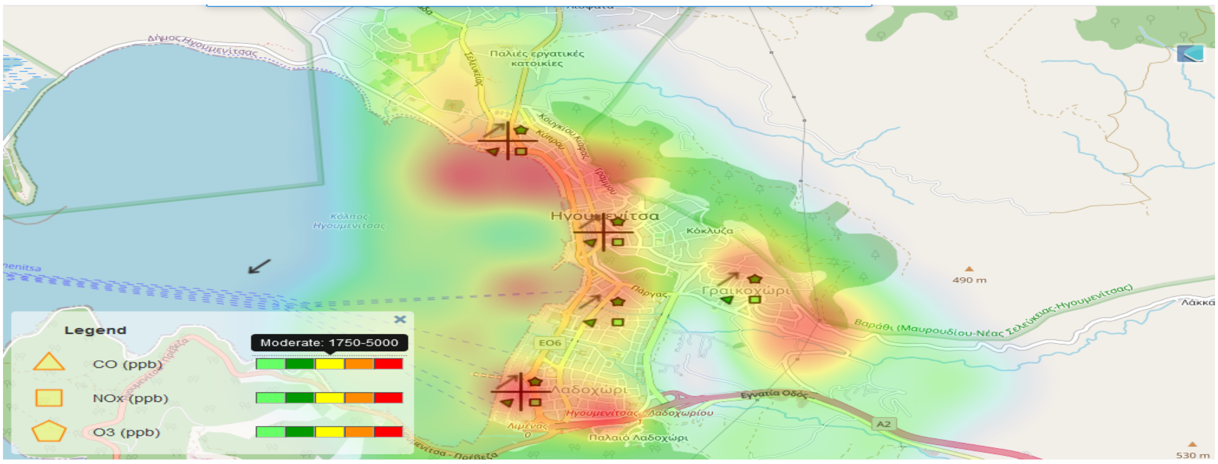

Fig. 3. Illustration of parameters using schematic – color techniques as well as using heatmap.

Fig. 4. Display the different layers of the platform that the user can alternate. On the left is the default Base Layer while on the right is the Raster Layer (above) and the Watermark Layer .

between Base Layers and to show or hide Overlays. The map of the platform has one Base Layer and four Overlays are displayed above it that are presented at Fig 4.

C. WebGIS-2D array

The second element of the web GIS platform is the 2D table in which all of measurements taken from the stations are displayed. Fig. 5 displays the 2D array that contents the data of the previous 4 days, the data of the current day, and a 2-day forecast in some variables as the forecasting service. This data, as in the map, is divided into 6 sets of 3 hours, which are represented as separate columns in the table.

The table also offers the user access to historical data from previous days using the column dates. The process of merging the data is illustrated in Fig. 5.

V. Summarisation an Future Works

This paper describes the technologies that we have used to develop an environmental monitoring platform and how it works. The main contribution of the platform can be the scalability and ease of modification. The platform was designed in such a way that almost all modifications and extensions are made quite easily. Modifications such as adding new stations, case study areas and displaying data from other providers require minimum development skills. It is mainly based on the proper use of configuration files, and minimum development interactions are necessary. With the use of open source applications, we succeeded in creating a platform allowing the strict European lows of GDPR to be easily fulfilled with no 3rd party obligations.

The system will be upgraded with further improvements, such as a warning system in case of measurements exceeding the desired limits, prediction models, and integration with vessel-tracking data from AIS (Automatic Identification System) in order to visualize the vessels which approach the ports and illustrate their impact on environmental measurements.

The future work of this paper includes the preparation of the dataset to be fed to neural networks and genetic algorithms, in order to show a forecast of specific parameters such as the CO or the PM_x. A number of approaches comprising the aforementioned methods as well as a Long short-term memory (LSTM) Recurrent Neural Network (RNN) will be used to show a prediction of the parameters. Finally, we aim to categorise the aforementioned parameters, in order to utilise classification algorithms.

Acknowledgment

This work was conducted within the framework of the project ECOPORTIL BMP1/2.3/2622/2017 (Environmental Protection of Areas Surrounding Ports using Innovative Learning Tools for Legislation), which was funded by INTERREG Balkan-Mediterranean - European Regional Development Fund.

This work is co-funded by project: “Enhancing research activities of Laboratory of Knowledge and Intelligent Computing” by Research Committee of University of Ioannina

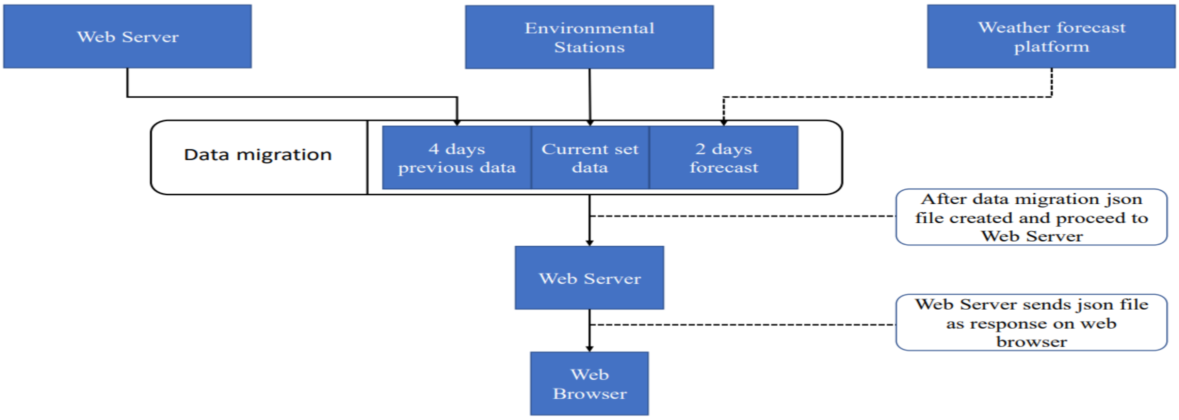

Fig. 5. Data migration from different sources that creates the data file for the 2D array.

Town Hall | Show graph

GFS 27 km	28/11. 6h	28/11. 9h	28/11. 12h	28/11. 15h	28/11. 18h	28/11. 21h	29/11. 6h	29/11. 9h	29/11. 12h	29/11. 15h	29/11. 18h	29/11. 21h	30/11. 6h	30/11. 9h	30/11. 12h
CO (ppb)	762.9	273.17	454.65	472.58	460.71	675.32	326.07	168.8	186.16	248.01	268.86	347.39	279.04	143.65	333.5
NO (ppb)	7.17	1.32	16.34	28.01	9.5	3.88	2.68	-3.1	-1.75	-3.3	-2.37	-0.27	-0.39	-0.5	7.64
NO2 (ppb)	27.37	24.32	24.16	20.29	32.68	37.24	21.57	26.73	22.72	30.45	34.27	29.97	24.75	21.55	20.84
O3 (ppb)	8.46	13.87	4.67	10.52	17.99	14.26	36.32	46.15	47.23	41.64	28.34	27.56	20.3	16.25	5.36
Temperature (°C)	10	9	13	21	19	15	14	15	16	16	14	15	13	12	15
RH (%)	66.65	68.25	61.22	45.67	50.64	61.03	52.75	55.63	50.7	57.71	71.38	68.47	77.56	78.8	69.68
P (mmHg)	765	765	765	764	763	763	761	759	758	758	756	757	758	758	759
G (°C)	841.67	1308.17	1271.93	1104.39	918.94	770.19	1690.94	1944.58	2115.56	1600.72	1044.65	1016.96	859.44	1014.95	980.19
PM1.0 (μg/m^3)	14.12	5.65	5.9	5.76	5.36	11.08	4.99	2.32	2.34	3.91	5.09	6.58	4.23	1.56	3
PM2.5 (μg/m^3)	19.21	7.91	8.2	7.87	7.23	14.99	6.71	3.04	3.02	5.22	6.92	9.02	5.9	2.2	4
PM10 (μg/m^3)	22.21	9.23	9.51	9.03	8.2	17.5	7.59	3.35	3.31	5.85	7.91	10.74	6.95	2.52	4.47
Wind Direction	↘	↘	↘	↙	←	↘	↘	↘	↘	↘	↓	↘	↓	→	↘
Wind Speed (Mph)	0	0	0	0	0	0	2	3	3	2	2	2	0	0	0
Wind Gusts (Mph)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

GFS 27 km	30/11. 15h	30/11. 18h	30/11. 21h	01/12. 6h	01/12. 9h	01/12. 12h	01/12. 15h	01/12. 18h	01/12. 21h	02/12. 17h	02/12. 20h	02/12. 23h	03/12. 02h	03/12. 05h
CO (ppb)	335.3	292.06	368.1	481.63	246.5	486.24	416.55	292.97	528.27	-	-	-	-	-
NO (ppb)	15.04	-0.86	-0.06	1.7	2.67	13.95	10.49	-0.64	-0.07	-	-	-	-	-
NO2 (ppb)	9.19	32.72	30.2	25.91	23.58	28.62	12.91	21.5	34.56	-	-	-	-	-
O3 (ppb)	23.16	34.43	23.25	13.08	12.4	4.83	16.56	40.36	27.09	-	-	-	-	-
Temperature (°C)	24	20	17	12	11	12	19	18	15	14	13	13	13	12
RH (%)	47.99	58.51	63.53	68.32	72.87	71.54	53.5	51.49	60.91	72	74	72	74	73
P (mmHg)	760	759	759	761	761	761	761	760	760	-	-	-	-	-
G (°C)	886.22	800	816.09	840.13	1105.4	1038.05	1017.42	1422.39	955.21	-	-	-	-	-
PM1.0 (μg/m^3)	2.24	1.01	6.29	7.9	5.1	6.28	4.68	2.76	9.41	-	-	-	-	-
PM2.5 (μg/m^3)	2.91	1.42	8.88	11.22	7.3	8.94	6.55	3.82	12.86	-	-	-	-	-
PM10 (μg/m^3)	3.2	1.65	10.69	13.87	8.36	10.67	7.6	4.32	14.99	-	-	-	-	-
Wind Direction	↖	←	↙	↘	→	↓	↖	↙	↓	↘	↘	→	→	→
Wind Speed (Mph)	0	0	1	0	0	0	0	1	0	8	6	5	5	5
Wind Gusts (Mph)	-	-	-	-	-	-	-	-	-	15	12	11	12	13

Fig. 6. The 2D array providing historical and current data.

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