Information System of Air Quality Assessment Using Data Interpolation from Ground Stations

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Abstract
Monitoring ground stations is crucial for creating interactive maps that assist in assessing air quality. A developed information system can aggregate and process the data obtained, which is then transformed into a unified format and used as input data for interpolation methods that create raster imagery. After processing, the data is stored in Amazon Simple Storage Service or database and can be retrieved using application program interfaces (APIs). The proposed architectural solution for creating the system includes a toolkit that can work with different volumes of data with ease. Using Docker during deployment provides additional capabilities for creating a flexible and scalable system. Specific tools such as PostGis and Geospatial Data Abstraction Library (GDAL) simplify the processing of data. For instance, GDAL helps with the interpolation, cropping, and tiling of the air quality raster image. The article describes the structure of the client part and the interface in detail. By using the Mapbox Graphics Library system, the system can easily visualize big data as a vector layer, helping users recognize hazardous zones and find safe places.

Keywords
Information system, air quality monitoring, docker, inverse distance weighting, data visualization

1. Introduction

Man-made disasters, such as industrial accidents or transportation incidents, can significantly impact air quality and lead to harmful health effects for nearby communities [1]. Efforts to prevent and mitigate these disasters are essential to ensure a safe and healthy environment for all. Air pollution is the biggest environmental health risk in Europe and has a significant impact on the health of the European population, especially in urban areas. Although emissions of major air pollutants and their concentrations in ambient air have decreased significantly over the past two decades in Europe, air quality remains poor in many regions. In October 2022, the European Commission proposed a revision of the Ambient Air Quality Directive, which included several key points:

- Stricter thresholds for pollution that are more in line with the new limits set by the World Health Organization.
- Improved access to justice and the right to clean air.
- Strengthened rules for air quality monitoring to support preventive action and targeted measures.
- Requirements to improve air quality modeling, especially in areas with poor air quality.
- Better public information [2].

It is necessary to create a system that display current air quality and hazardous areas for person to be located. Having collected historical and current data, it is necessary to provide information about pollution at the point.

The developed information system processes the collected data from ground stations around the world and calculates the AQI (Air quality index) interpolation layer in real time. The novelty of this article is methodology of information system creating by using mathematical models which calculate pollution spreading. As a result, weather research and forecast (WRF) model were set up for Ukraine. Forecast results were compared with forecast result of autoregression integrated moving average model. The created system is used for storing data, modeling and air quality forecasting. Also, this system can help government detect problematic parts caused by energy and resource extractive industry and else. Aggregating and visualization processed data give opportunity to access and compare results of implemented environmental reforms and innovations in the regions.

2. Related works

For today, many studies have been conducted with methods for assessing air quality and the factors that most affect air quality. There are a lot of studies which try to solve a problem of lack on-time data [3-8]. In paper [9], the authors compared local and global methods for calculating the air quality index using the example of the city of Dhaka. The findings of this study suggest that the local AQI more accurately reflects the air quality in the corresponding study area under certain real-world scenarios. In [10], the authors classified and analyzed data on monitoring emissions of harmful substances in the Lviv region and created a series of environmental maps based on atmospheric air monitoring data in the Lviv region. In paper [11], the authors propose a method for predicting air pollution concentrations in unmonitored areas using spatial interpolation tools in GIS. This provides valuable information on the dispersion of air pollution. The study in [12] presents recent spatiotemporal changes in the AQI and air quality in Chongqing's main urban area. A complete dataset was reconstructed using a novel method (LRTC-TNN) to interpolate missing values. In paper [13], the authors compare a model that uses the highest sub-index depending on USEPA pollutants standards with a model that includes the weights of all pollutants as an aggregated air quality index (AAQI) model. The AAQI is a comprehensive indicator of air quality and is more useful in environmental management as it represents multiple air quality pollutants. In [14], the authors focus on the management strategy of the environmental ecosystem under the Artificial Intelligence (AI) algorithm and explore the correlation between air quality and meteorology. The experimental analysis reveals that the average temperature has a positive correlation with the AQI, while relative humidity and wind speed have a negative correlation with AQI. Furthermore, the proposed RF + BP + GA model's prediction error for AQI is no more than 0.32, indicating an excellent fitting effect with the actual value. In paper [15], the authors explores that the agricultural sector has a significant impact on the air quality index using the AgrImOnIA (Agriculture Impact On Italian Air) framework. This framework assesses the role of the livestock sector in air quality in the Lombardy region and enables comparisons with other European regions.

Earth remote sensing has become a powerful tool for various application areas such as soil moisture assessment [16], agricultural monitoring, and air quality assessment. There are numerous satellite data that can indicate criteria for air pollutants (e.g., PM2.5 and NO2) and greenhouse gases (e.g., CH4 and CO2). An example of such a satellite is Sentinel-5. It is an atmospheric monitoring mission under the European Copernicus program, formerly the GMES (Global Environmental and Safety Monitoring) program [17]. It provides accurate measurements of major atmospheric components such as nitrogen dioxide, carbon monoxide, ozone, methane, formaldehyde, sulfur dioxide, and aerosol properties. But most satellite devices cannot distinguish pollution near the surface of the earth from pollution which is on the upper layer in the atmosphere.

3. Air quality index calculation

The Air Quality Index – imaginary unit of measure, which is used by government agencies or private companies to inform citizens about the level of air pollution. Different countries have their own indicators of air quality in accordance with national standards.

In general, the lower the AQI, the better the air is considered. If this index increases, then a significant part of the population faces health risks caused by dirty air.

That is, AQI is a unit used by the international community to highlight how polluted the air is at the current time (or how polluted it will be in the near future according to forecasts). The US AQI was chosen, which was developed by the EPA (Environmental Protection Agency) to facilitate understanding in the current information system. It is divided into six categories, each of which has its own impact on health.

Its formula usually takes into account six main pollutants:

- particulate matter $PM_{2,5}$;
- particulate matter PM_{10};
- carbon monoxide (CO);
- sulfur dioxide (SO_2);
- nitrogen dioxide (NO_2)
- ozone (O_3).

For each of these pollutants, the Environmental Protection Agency has established national air quality standards aimed at protecting public health. Table 1 below shows the levels of indices and explanations:

Table 1
AQI categories with description

Name	Value range	Description
Good	0-50	Air quality is considered satisfactory. Air pollution poses little or no risk.
Moderate	51-100	Air quality is acceptable; it is important to note that for certain pollutants, there may be a moderate health concern for a very small number of individuals who are particularly sensitive to air pollution.
Unhealthy for sensitive group	101-150	Individuals who are part of sensitive groups may experience certain health effects due to air pollution, while the general public is not likely to be affected.
Unhealthy	151-200	Although everyone may experience some health effects due to air pollution, individuals who are part of sensitive groups may experience more severe or serious health effects.
Very unhealthy	201-300	Hazardous for your health!
Hazardous	>300	Hazardous for your health (emergency conditions)! The entire population is at risk of being affected by the health effects of air pollution.

The quality index shows the corresponding health risk against each pollutant at this point in time. The Air Quality Index is determined by calculating the highest value for each pollutant using the following method:

- Recognize the highest concentration of all monitors in each reporting area and round as follows: CO (ppm) – truncate to 1 character, ozone (ppm) – truncate to 3 characters, PM_{10} ($\mu g/m^3$) – truncate to integer, $PM_{2.5}$ ($\mu g/m^3$) – truncate to 1 character, NO_2 (ppb) – truncate to integer, SO_2 (ppb) – truncate to integer.
- Using Table 2, we find the interval in which the current concentration is included;
- Using equation 1, we calculate the value of the index:

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} \left(C_p - BP_{Lo} \right) + I_{Lo} \ ,$$

(1)

where I_p is the value of index for pollutant p, C_p is the index for pollutant p, BP_{Hi} is the concentration breakpoint (is greater than or equal to C_p), BP_{Lo} is the concentration breakpoint (is less than or equal to C_p), I_{Hi} is the AQI value corresponding to BP_{Hi}, I_{Lo} is the AQI value corresponding to BP_{Lo};

- Round the index to the nearest integer.

Table 2
Breakpoints for the AQI

O3 (ppm) 8-hour	O3 (ppm) 1-hour	PM2.5 (µg/m3) 24-hour	PM10 (µg/m3) 24-hour	CO (ppm) 8-hour	SO2 (ppb) 1-hour	NO2 (ppb) 1-hour	AQI
0.000- 0.054	-	0.0 – 12.0	0 - 54	0.0 - 4.4	0 - 35	0 - 53	0 - 50
0.055 - 0.070	-	12.1 – 35.4	55 - 154	4.5 - 9.4	36 - 75	54 - 100	51 - 100
0.071 - 0.085	0.125 - 0.164	35.5 – 55.4	155 - 254	9.5 - 12.4	76 - 185	101 - 360	101 - 150
0.086 - 0.105	0.165 - 0.204	55.5 - 150.4	255 - 354	12.5 - 15.4	186 - 304	361 - 649	151 - 200
0.106 - 0.200	0.205 - 0.404	150.5 - 250.4	355 - 424	15.5 - 30.4	305 - 604	650 - 1249	201 - 300
-	0.405 - 0.504	250.5 - 350.4	425 - 504	30.5 - 40.4	605 - 804	1250 - 1649	301 - 400
-	0.505 - 0.604	350.5 - 500.4	505 - 604	40.5 - 50.4	805 - 1004	1650 - 2049	401 - 500

4. Weather prediction

Weather Research and Forecasting (WRF) was chosen as the weather forecasting model, a next-generation numerical weather forecasting system developed for both atmospheric and operational forecasts. WRF can perform simulations based on actual atmospheric conditions or idealized conditions. WRF offers an operational forecasting flexible and computationally efficient platform reflecting the latest advances in physics, numerical solutions and data assimilation made by developers from a wide community of researchers [18]. Scheme of WRF is visualized in Figure 1.
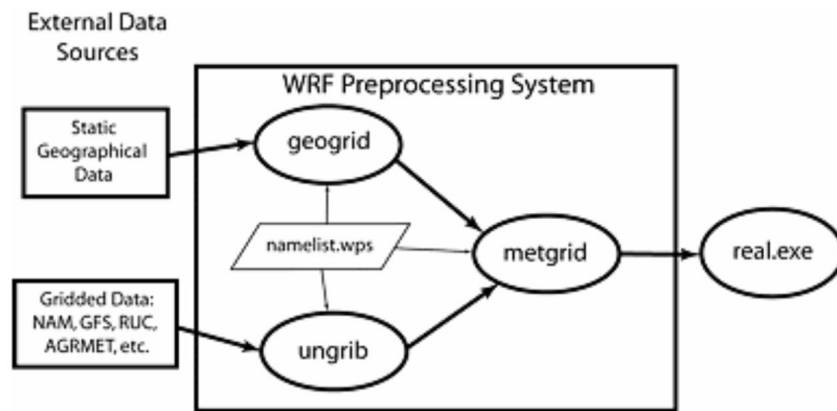

Figure 1: WRF scheme of work

To adjust the model, the data of its forecasts for the past were compared with the real readings of the state weather stations of Ukraine. Using the Python programming language, interpolation was carried out between these points. These models were compared with data from real sensors in such parameters as: Temperature (2m from the ground); U wind; V wind; humidity; pressure.

It was decided to compare the results of the predictive model with the forecast of autoregressive models used to describe stationary stochastic processes. The ARMA (Autoregressive moving average) model is a combination of AR and MA models. AR(p) – a model describing the process under study at a time that depends on the values p of previous time intervals [19]:

$$y_t = \beta_1 t_{t-1} + \beta_2 t_{t-2} + \cdots + \beta_p t_{t-p} + \varepsilon_t \qquad (2)$$

where $\beta_1, \beta_2, \ldots, \beta_p$ – constants, ε_t – random error.

The MA model represents a stationary process as a linear combination of consecutive white noise values. This model is useful as a supplement to autoregression models for a more detailed description of the noise component. The model is expressed by the following equation:

$$y_t = \varepsilon_t - \gamma_1 \varepsilon_{t-1} - \gamma_2 \varepsilon_{t-2} - \cdots - \gamma_q \varepsilon_{t-q}, \tag{3}$$

where $\gamma_1, \gamma_1, \ldots \gamma_1$ – model params.

On the autocorrelation graph in Figure 2 is shown that the data doesn`t have a tendency and allows us to conclude that the investigated series is stationary (the stationary series must have a constant average and must oscillate around this average with constant variance).
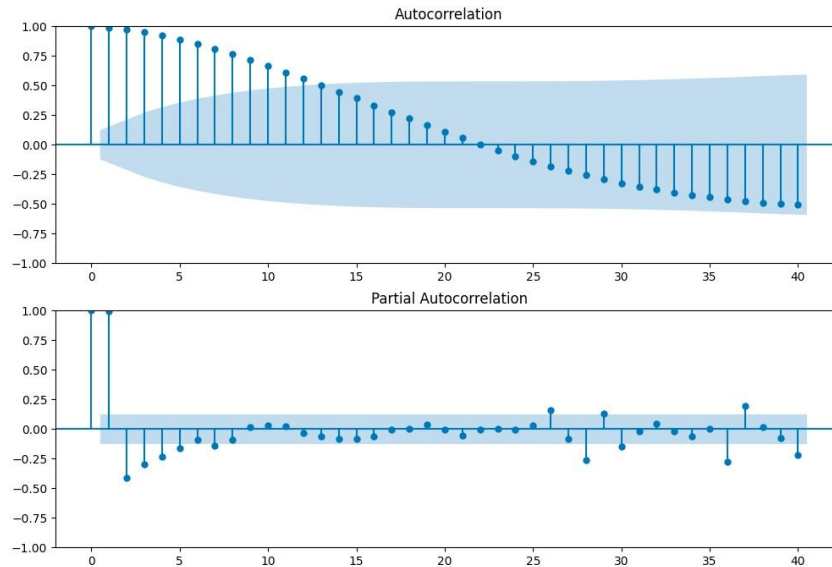

Figure 2: Autocorrelation and partial autocorrelation plot

As time series is stationary, ARIMA (Autoregressive integrated moving average) model must be used with degree of differencing 0. It use difference of raw observations to make time series stationary. ARIMA has 3 input params:
- p – order of autoregression model;
- d – degree of differencing;
- q – order of moving average model.

To compare we used ARIMA(3, 0, 3) model to predict temperature and compare with WRF.
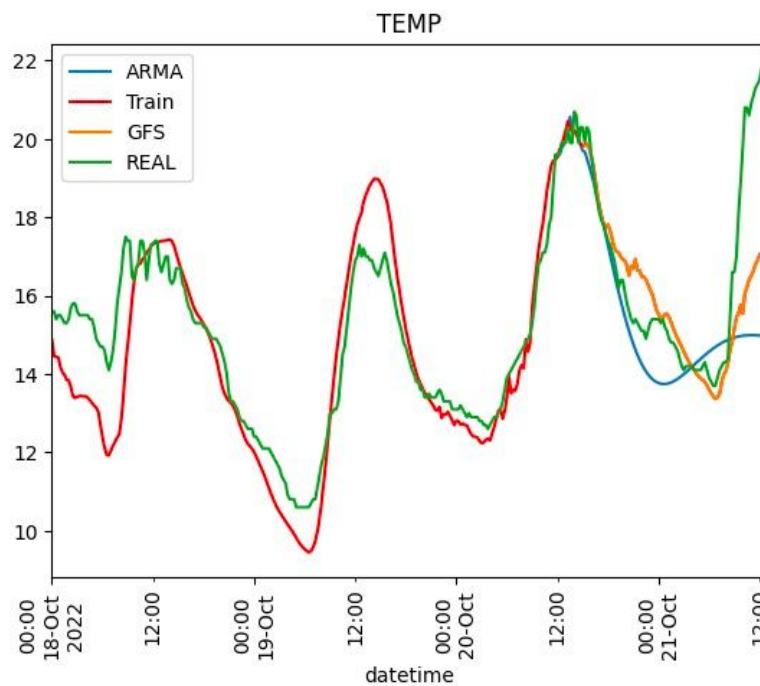

Figure 3: Forecast comparison

In Figure 3 is shown that difference between the WRF and ARIMA lower that one degree, so root mean square errors were calculated to access quality of their prediction: WRF-GFS model has approximately 1.2858, when ARIMA model has only 1.33, so it is mean WRF is more accurate than ARIMA model, but it can be improved by using postprocessing like Multi-sensor Advection Diffusion of using satellite observations to detect the clouds and advect and diffuse the clouds [20].

5. Interpolation methods

Interpolation tools provide the ability to create a continuous (or predictable) surface by value from anchor points. Measuring the height, magnitude or concentration for the observed objects and phenomena, at each point of the studied territory, is usually difficult or very expensive. Instead, system can measure indicators at anchor points distributed over the surface and predict values that can be assigned to everyone else. Input points can be located either as a regular grid or randomly.

Deterministic interpolation methods calculate the result based on the measured values that fall into the vicinity of the interpolated point, and on given mathematical formulas that determine the smoothness of the resulting surface. Deterministic methods include IDW (inverse distance weighting) algorithms (inversely weighted distance method), Nearest Neighbor (nearest neighbor method), Moving Average and Linear (linear interpolation). Geostatic methods are based on statistical models that include the analysis of autocorrelation (statistical relations between points that are measured). As a result of this, geostatistical methods not only have the ability to create a surface of the predicted values, but also provide an opportunity to determine the accuracy of the forecast. For example, Kriging and its modifications are one of the most well-known methods of interpolation.

Inversely weighted distance method – weighted average interpolator. You must provide as input the values of the scattered data, including the coordinates of each data point and the geometry of the output grid. The function will calculate the interpolated value for the specified position in the output grid. For each grid node, the resulting value of Z will be calculated using the formula:

$$Z = \frac{\sum_{i=1}^{n} \frac{Z_i}{r_i^p}}{\sum_{i=1}^{n} \frac{1}{r_i^p}}, \tag{4}$$

where Z_i is known point value i, r is the distance from the grid node to the point i, p is weighting power, n is number of points in Search Ellipse. The smoothing parameter s is used as an additive term in the Euclidean distance calculation:

$$r_i = \sqrt{r_{ix}^2 + r_{iy}^2 + s^2}, \tag{5}$$

where r_{ix} and r_{iy} are the horizontal and vertical distances between the grid node to i.

In this method the weighting factor w is

$$Ew = \frac{1}{r^p}. \tag{6}$$

In order to find out the value of the pollution index at a point other than the point of location of the station, which provided information on pollutants, the IDW interpolation algorithm was chosen, namely its implementation in GDAL. GDAL is a translator library that can read and write geospatial data in both raster and vector formats. It provides a unified data model for these formats, allowing applications to work with a variety of different geospatial data formats through a single API. In addition to the library, GDAL also includes a number of command-line utilities for manipulating and processing geospatial data [21].

All operations with vector and raster are carried out in the virtual memory of the library, which made it possible to avoid writing files to the hard disk. By transferring the polygon and the type of pollution index for calculation as a result, we obtain a raster with the results of interpolation, which is shown in Figure 4.
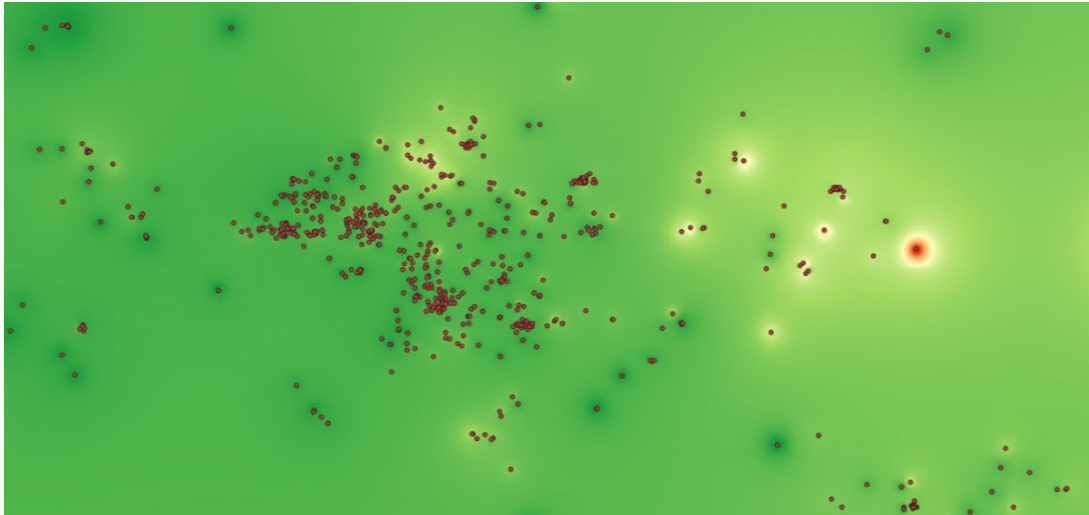
Figure 4: Interpolation of the air quality index (points - location of ground stations)

The following manipulations were performed with the raster image:
• crop regions where there is no data from land stations (countries in Africa, the Middle East, South America) and water resources (seas, rivers, oceans), shown in Figure 5;
• color scheme settings;
• cutting a raster image into tiles (forms folders with files that are loaded with a certain card zoom) for faster rendering.

Figure 5: System displays interpolation results as a bitmap layer on the map

Mask is used to exclude areas which don't have enough points to get the result. So, users weren't confused by abnormal values for that region.

6. Development techniques

To visualize the intermediate results and format the source files of the system, the Python programming language, version 3.7, was chosen. Due to the ability to split programs into modules, the

Python language allows you to use them in other programs. The large library of standard modules contained in Python is a great foundation for new applications, and the large community helps you get started with this language easily. Standard modules include many convenient tools for working with files, system calls, interfaces to various graphical libraries and network connections.

Django is a Python-based high-level web framework that aims to assist developers in building web applications as efficiently as possible, from concept to completion. One of Django's core focuses is on security, and it provides developers with tools to help avoid common security pitfalls and vulnerabilities. Corresponds to the architectural scheme of the model template views (MTV). Django's main goal is to make it easier to create complex, database-driven websites. The framework emphasizes the reuse and "connectivity" of components, fewer code, low connectivity, rapid development, and SOLID principles. Django also provides an additional administrative interface for creating, reading, updating and deleting data, which is dynamically generated through introspection and configured using administrator models.

Django is compatible with several web servers such as Apache, Nginx using WSGI, Gunicorn or Cherokee using flup. It can also be run with a FastCGI server which supports web servers like Lighttpd or Hiawatha. In addition, other WSGI-compatible web servers can be used. The framework supports four databases: PostgreSQL, MySQL, SQLite, and Oracle, while Microsoft SQL Server can be used with django-mssql on Microsoft operating systems. External tools are also available for IBM Db2, SQL Anywhere and Firebird [22]. PostgreSQL, which is one of the officially supported databases, is an open-source object-relational database that extends the SQL language with many features to safely store and scale complex data loads.

PostgreSQL is widely recognized for its robust architecture, high level of reliability, and its ability to maintain data integrity. Its feature set is also considered to be highly dependable. As a result, PostgreSQL has earned a strong reputation in the industry. PostgreSQL runs on all major operating systems, is ACID compatible since 2001, and has powerful applications such as the popular PostGIS geospatial database extender. Not surprisingly, PostgreSQL has become an open-source relational database to choose from for many people and organizations [23]. PostgreSQL is equipped with many features aimed at helping developers build applications, administrators to protect data integrity and build bounce-resistant environments and help manage your data no matter how large or small the dataset is. PostgreSQL tries to comply with the SQL standard when such compliance does not contradict traditional features or can lead to poor architectural solutions. Many of the functions required by the SQL standard are supported, although sometimes they have slightly different syntax or functions.

PostGIS is a spatial database extender for PostgreSQL that enables the storage and manipulation of spatial data, such as points, lines, and polygons. It enhances PostgreSQL with new types (such as geometry, geography, and raster), functions, operators, and indexes that are specifically designed for spatial data. With PostGIS, users can perform spatial queries, manipulate spatial data, and perform complex spatial analysis using SQL. It is widely used in geographic information systems (GIS), web mapping applications, and location-based services. The list of functions of PostGIS 2+ includes:

- Processing and analysis of both vector and raster data for splicing, morphing, reclassification and collection/merging with SQL power;
- Spatial reprojection of SQL-functions called by both vector and raster data;
- Support for importing and exporting vector data of ESRI (Environmental Systems Research Institute) files using batch command line and GUI tools and support for other formats with third-party open source tools;
- Command line for importing raster data of many standard formats: GeoTiff, NetCDF, PNG, JPG;
- Visualization and import of vector data support features for standard text formats such as KML, GML, GeoJSON, GeoHash and WKT using SQL;
- SQL functions for obtaining pixel values by geometric domain, statistics by region, clipping raster elements by geometry and vectorization of rasters;
- Support for network topology.

Docker Engine is an open source container technology for creating and containerizing your applications. Docker Engine acts as a client-server program with a working docker process, APIs that specify interfaces that programs can use to communicate and transmit instructions to the Docker daemon, Dock server client command line interface (CLI).

The Command Line Interface utilizes the Docker API to manage and communicate with the Docker daemon through scripts or direct CLI commands. Other Docker applications also use APIs and CLIs as their basic interface. The Docker daemon is responsible for creating and managing Docker objects, such as images, containers, networks, and volumes.

Docker Compose is a tool that enables the description and execution of multi-container Docker applications. With Compose, you can configure the services for your application using a YAML file. Once configured, you can create and run all of the services from your configuration with a single command.

Compose has commands to manage the entire lifecycle of your application, including:
- start, stop and restore services;
- view the status of running services;
- streaming log output of running services;
- launch a one-time command on the service.

Memcached is a repository of key-value pairs in memory for small portions of arbitrary data (strings, objects) based on database calls, API calls, or page visualization. Its simple design contributes to rapid deployment, ease of development, and solves many problems with large data caches. Its API is available for most popular languages.

The server part is divided into three components. The first is the backend on Django. The second includes docker settings for deployment. The third is the frontend. Git was selected as the version control system and created three separate repositories for each component using submodules.

The deployment application includes docker files and script files that are responsible for running each container. All container data is described in the docker-compose file, including cache, frontend service, Django application, database, worker database, and more.

7. Description of the information system

The client part is implemented using the Angular framework, which gave it the following advantages: hierarchical structure of modules [24], partitioning client parts into 3 layers: presentational (responsible for displaying data in the system), abstract (a method for the interaction of the main and presentation layers) and main (responsible for working with data), since the web application – SPA manages the transfer of data and not views. The system implements data caching, which makes it possible to speed up data exchange between the client and the server.

The components themselves are divided into "smart" and "dump" components: one part of the components can perform certain data manipulations, access the API and others, while the other can only display data from the parent component. Using this approach gave the following advantages:
- the ability to reuse is always considered the main advantage of most programming approaches;
- adherence to the principle of D.R.Y (Don't Repeat Yourself) means that you can quickly and efficiently add the same functionality to different areas;
- refactoring a part or an entire application requires changes only in fewer locations;
- readability;
- facilitates coverage by tests.

At the component level, a single-directional data stream is configured (data is sent down the component tree, up – events caused by the user during interaction with the system), which is shown in Figure 6.

The following data is submitted to the output of the information system: raster tiles of the constructed interpolation of the air quality index, enriched on Amazon S3, and data on stations transmitted via HTTP requests.

NgRx is used to control the current state, which allows you to reactively track changes. The scheme of the state manager is shown in Figure 7.

To display data to the user, the system uses the Mapbox GL JS library. When receiving station data from the server, they are serialized and brought to the GeoJSON format, and then displayed as a vector layer on the map, as shown in Figure 8.

To save on system performance, it was decided to apply clustering to the stations – to group the stations into a common marker (cluster). Mapbox GL uses greedy clustering as the basis of the

clustering algorithm, which works as follows: any point from the data set is selected, all points in a certain radius around this point are located; a new cluster with adjacent points is formed, a new point is selected that is not part of the cluster, and the previous steps are repeated until all points are visited [25].
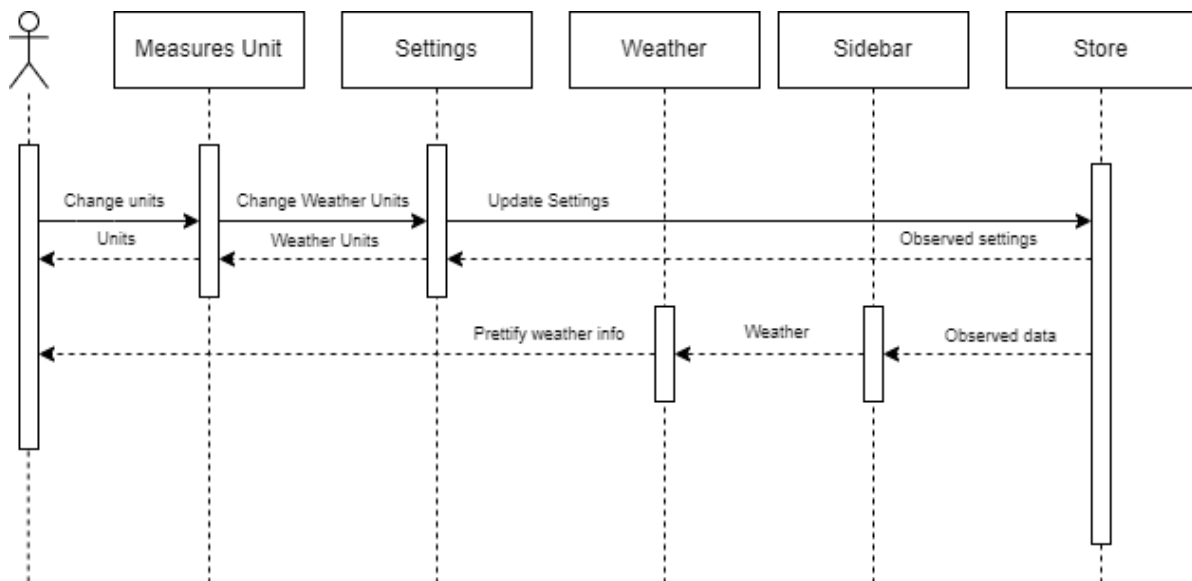

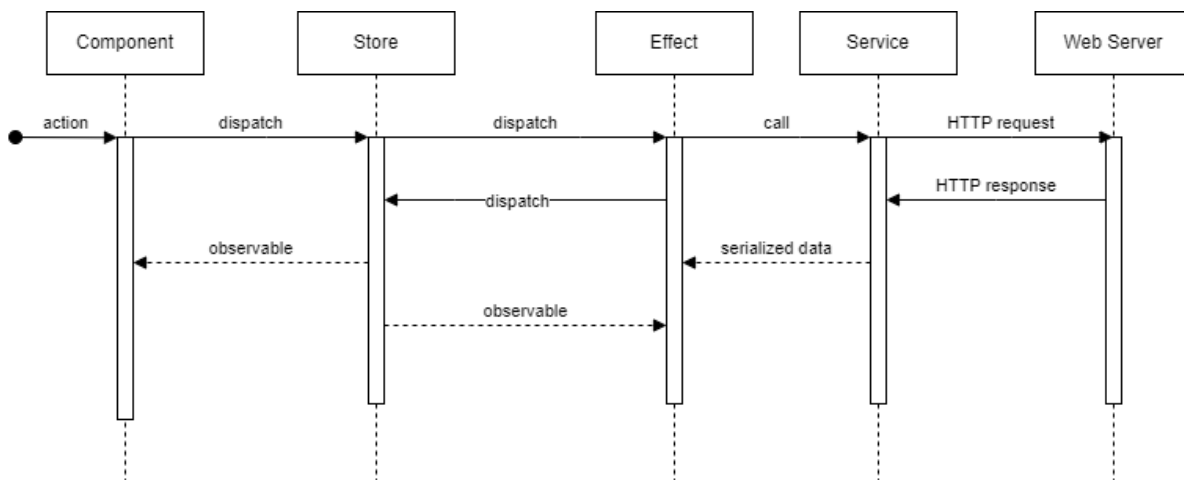**Figure 6:** An example of data exchange between components

Figure 7: The scheme of the state manager

When user click on the cluster, the map is tampered with until the cluster clicked by the user disappears. If the user clicked on a marker that is not a cluster, a modal window with information about this station and a panel is opened that shows the daily indicators (minimum, maximum and average) of the air quality index during the week (the data interval depends on the frequency of surveying / updating the station). This functionality is shown in Figure 9.

In addition, the system has the ability to change the language (available Ukrainian and English), the ability to save the current state of the map as a raster image to the working machine, switch to other modes:

- Fire map;
- Pollution modeling map in Kryvyi Rih;
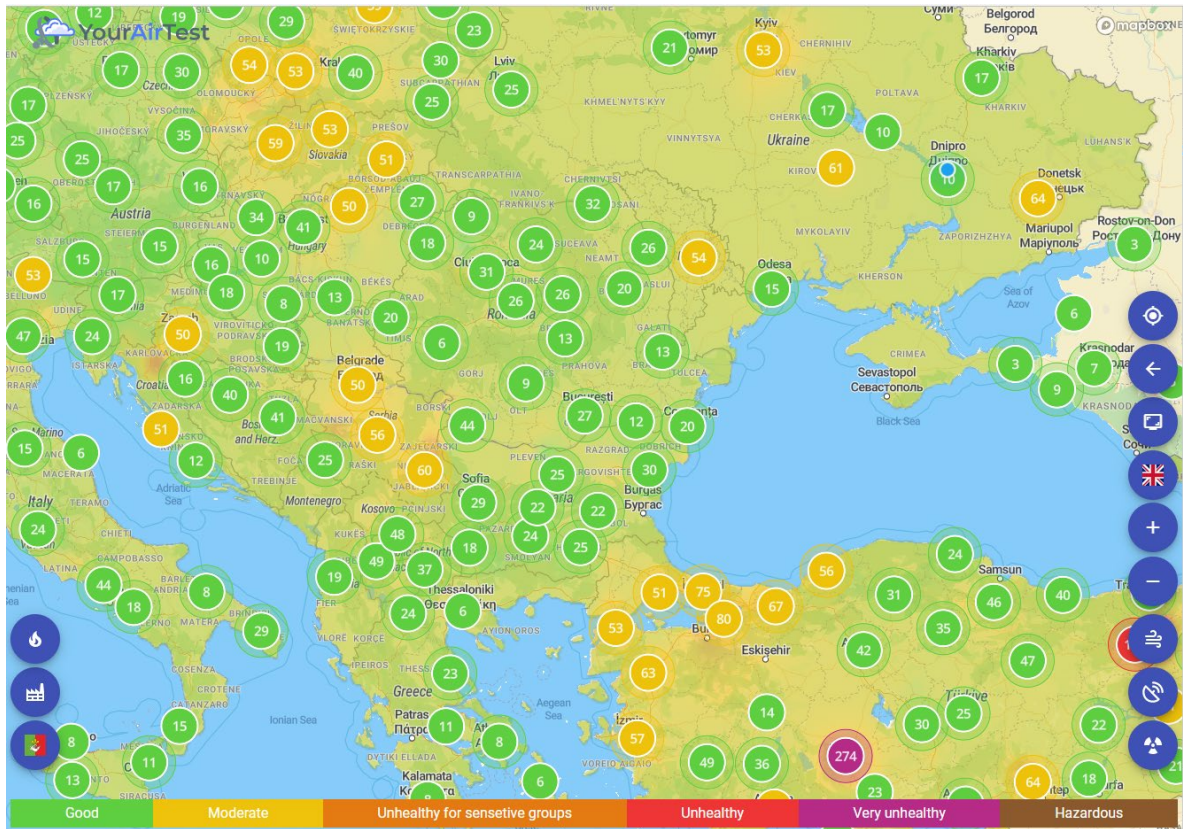- Radiation contamination map.

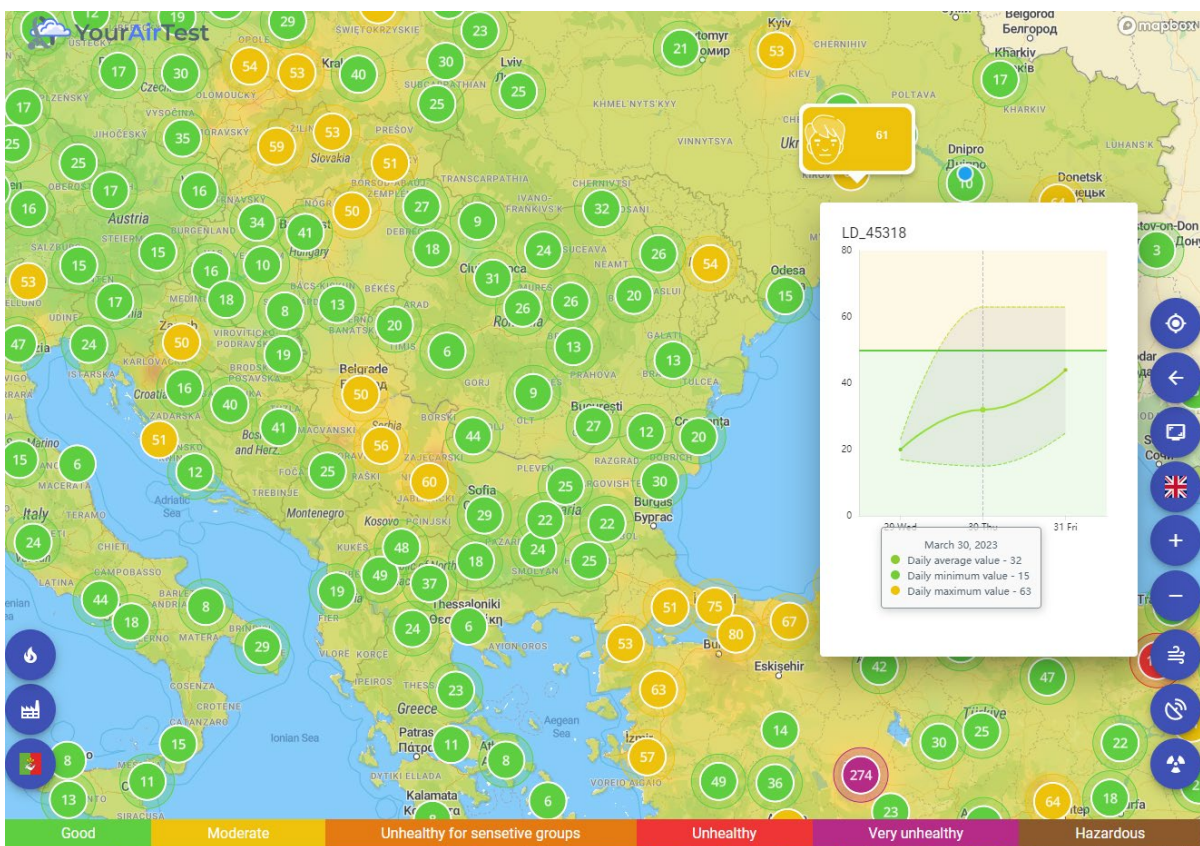**Figure 8:** Map with ground stations in Eastern Europe

Figure 9: Station information is displayed after clicking on the marker

8. Conclusion

The developed air quality monitoring system allows you to aggregate and analyze data. The analysis involves averaging the values of pollutant concentrations and the subsequent calculation of the air quality index according to European and American standards, etc. Pollution maps were created using deterministic interpolation methods such as IDW or Geostatic methods such as Kriging and its modifications. As an additional post-processing (in addition to specifying the color scheme), mask trimming and tiling operations are used.

Weather research and forecast model were used for predicting temperature used data from Ukrainian data stations. The results of forecasting were complained with ARIMA forecast, that in result get worse quality of prediction. In future we are going to improve prediction of WRF using neural network as postprocessing tools to prevent mathematical deviation of model.

The task of scaling and deploying on the server using docker is facilitated. For today all infrastructure ran altogether as monolith system. After forecast improvement we will try to make system more flexible and stable by separate parts of projects in its own server instances, but such solution can cause a lack of finances.

The described architecture and results of modeling are used in the YourAirTest air monitoring system.

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