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DEVELOPMENT AND EVALUATION OF THE LOCAL AIR QUALITY FORECAST SYSTEM

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Abstract: We have developed operationally working local air quality forecastsystem thatconsists of several meteorological and air quality data retrieval and storage components, emission, dispersion and chemistry models, as well as, post-processing tools. The 44 hour forecasts are provided for themost important air pollution species four times a day into a grid covering the Helsinki metropolitan area.The performance of the local air quality forecast system was evaluated with the comparison of forecasted and observed PM_{10}concentrations in the spring 2011. The system is able to predict the daily variability of the PM_{10} concentrations fairly well, e.g., the index of agreement (IA) was 0.76 at Vallila, 0.80 at Leppävaara, and 0.53 at Mannerheimintie. However, concentrations were under-predicted in all three locations.The results point out the most critical factors for reliable air quality forecasting and especially the challenges with PM_{10} forecasting.

Key words: *forecast, model, air quality,* PM_{10}

INTRODUCTION

Generally the air quality models have been valuable tools for regulatory purposes, policymaking, and research applications. Air quality models areused, for example, to study emission reduction scenarios and as a help of defining when and where the monitoring campaigns and stations should be placed.Besides, using the air quality models as information and planning tool for authorities, they can be also used directly to inform and warn the public about potential high air pollution concentrations. To provide information and warnings for public, air pollutant concentrations need to be forecasted operationally and shown for example on web page. Thus air quality forecasting requires aseries of different models,from meteorological forecasting to dispersion of air pollutants, as well as data retrieval and processing tools.

A number of air pollutant forecast systems have been developed during the past years.For example, the operational air quality forecast system (THOR) has been developed at the National Environmental Research Institute, Denmark (Brandt et al, 2001). It produces three days air pollution forecast on different scales four times a day. The Norwegian Institute for Air Research has developed the operational air quality forecast system (AirQUIS) that provides 48 hour forecast once a day for several air pollutants (Berge et al., 2002).In the USA, the air quality forecast system AIRPACT (Air Indicator Report for Public Awareness and Community Tracking) providesone to three days air quality forecasts once a day for the Pacific Northwest region (AIRPACT, 2011; Vaughan et al., 2004).

The local air quality forecast system developed in the Finnish Meteorological Institute (FMI)provides 44 hour forecasts forNO_2, NO, CO,O_3, $PM_{2.5}$,and PM_{10}four times a day. It calculates concentrations in a grid containing about 18700 receptor points at the Helsinki metropolitan area.The system utilises meteorologicalforecasts from HIRLAM, background concentration forecastsfrom SILAM, and air quality measurements from the national air quality portal. The traffic emission model includes exhaust emissions of NO_x, CO, and $PM_{2.5}$, and suspension emission of PM_{10}. A road network dispersion model CAR-FMI (Contaminants in the Air from a Road; Härkönen, 2002) is applied for dispersion of pollution originating from vehicular traffic.

We have evaluated the air quality forecast system against observed PM_{10}concentrationsat three locations (Vallila, Mannerheimintie, and Leppävaara)in the Helsinki metropolitan area.The study period was from 24 March to 30 April 2011. In addition to PM_{10}, the meteorological data used as an input in the system have been shortly evaluated.

MATERIALS AND METHODS

Data

The meteorological data is forecasted by the High Resolution Limited Area Model(HIRLAM) to the weather station at Helsinki-Vantaa airport. The data is forecastedfor 48 hours four times a day. All meteorological boundary layer parameters needed in the air quality modelling are obtained directly from the HIRLAM model, except the inverse Monin-Obukhov stability parameter and the friction velocity that are computed by the air quality forecast system.

The System for IntegratedmodeLling of Atmospheric coMposition (SILAM) is applied for the background concentration data. NO_2, NO, O_3, CO, $PM_{2.5}$, and PM_{10} concentrations are forecasted to the regional background station Luukki for 72 hours once a day.The observed background concentrations for NO_2, NO, O_3, and $PM_{2.5}$ from the monitoring station of Luukki are gathered from the national air quality portal. Observed background concentrations are used in correction of forecasted background concentrations. For PM_{10} and CO there is no regional background concentration available. Therefore for PM_{10}, observed $PM_{2.5}$ concentrations are used in calculation of the correction coefficient, and for CO, no correction is used.Forecasted background concentrations are corrected by the ratio of the previous available 24 hour observed and forecasted concentrations.

Models

The Gaussian finite line source modelCAR-FMI (Contaminants in the Air from a Road; Härkönen et al., 1995; Härkönen, 2002) is applied for dispersion of traffic-originating pollutants. The CAR-FMI includes a dispersion model, chemical transformation model, and dry deposition of particulate matter. The dispersion parameters are modelled as function of the Monin–Obukhov length, the friction velocity and the mixing height (Gryning et al., 1987). Traffic-originated turbulence is modelled with a semi-empirical treatment (Petersen, 1980). The chemical transformation model contains basic reactions for NO_x, O_2, and O_3.

The traffic emission model is based on the CAR-FMI (PC) emission module (Härkönen, 2002). The emission model includes exhaust emissions of gaseous compounds CO and NO_x, and fine particulates ($PM_{2.5}$). The vehicular emissions are modelled to be dependent on vehicle travel speed, separately for the main vehicle categories (passenger cars and vans, busses, and trucks). The emission factors are based on the nationally conducted laboratory measurements of vehicle emissions (Laurikko, 1998; Laurikko et al., 2003). The emission rate (µg m^{-1} s^{-1}) of the line source is the product of number of vehicles per hour and emission factor (µg veh^{-1} m^{-1}) summed over the emission categories (Härkönen, 2002). In case of PM_{10}, also an emission factor for suspension (µg veh^{-1} m^{-1}) is taken into account.

The emission factors for suspension are modelled by considering the moisture content of the road surface and the particles origin from the wear of pavement and from the traction sand. The suspension emission model used in FMI (Kauhaniemi et al., 2011) is based on the particulate emission model of the Swedish Meteorological Institute, SMHI (Omstedt et al., 2005). The emission factor for suspension of road dust is computed separately for so-called sanding (Oct-May) and non-sanding (Jun-Sep) periods. The baseline for the model is set bythe reference emission factors that depend on the period(sanding and non-sanding), the size of particles (PM_{10} and $PM_{2.5}$), and traffic environment (urban/highway). For now, we use the suspension model only for computation of PM_{10} and the reference factors evaluated by Omstedt et al. (2005) for Stockholm (i.e., 200 and 1200 µg $veh^{-1}m^{-1}$, for non-sanding and sanding periods, respectively).

In addition to the models, the local air quality forecast system contains several data service and post-processing tools to gather data from the different databases and to produce informative text and graphs regarding air quality in past, present and forecasted situation.

RESULTS

The local air quality forecast system provides 44 hour forecasts for air pollutant concentrations in the grid containing 18760 receptor points in the Helsinki metropolitan area. Figure 1 shows an example of the spatial distribution map of the hourly average PM_{10} concentrations on 11 April 2011(at 16local time)in the Helsinki metropolitan area. Concentrations were forecasted on 11 April 2011 (at 14 local time). For now, the concentration map was created manually by using the MapInfo software, but in the further, similar concentrations maps could be created automatically and presented, e.g., on webpage.

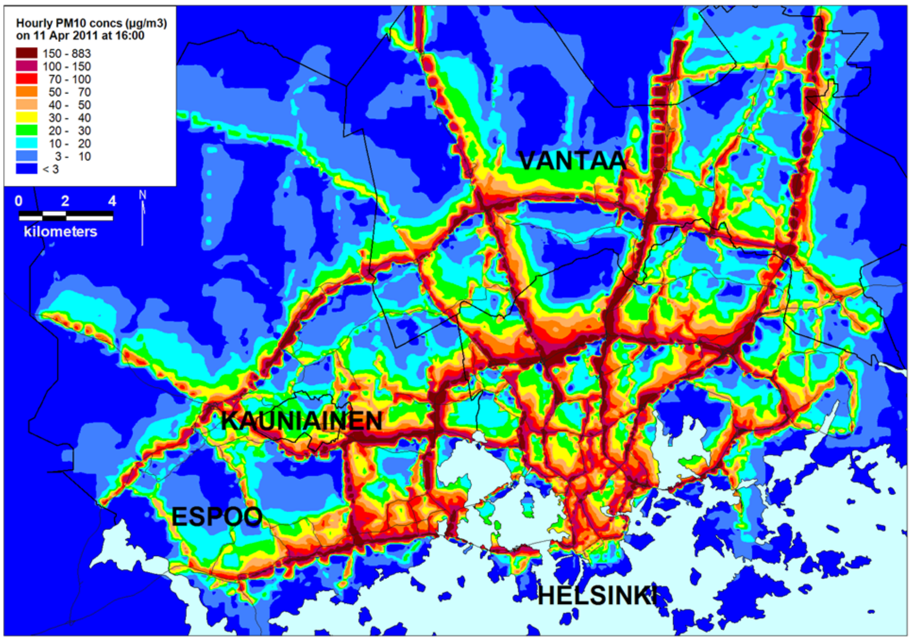
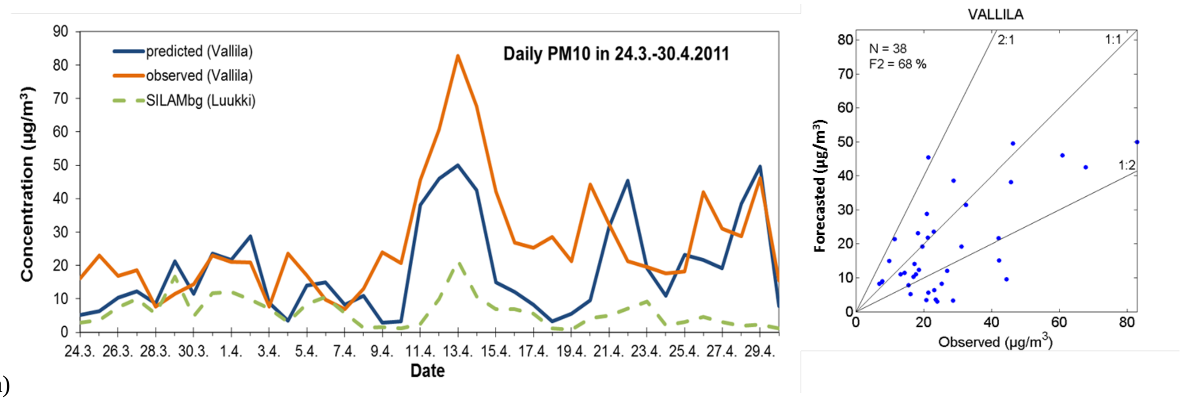


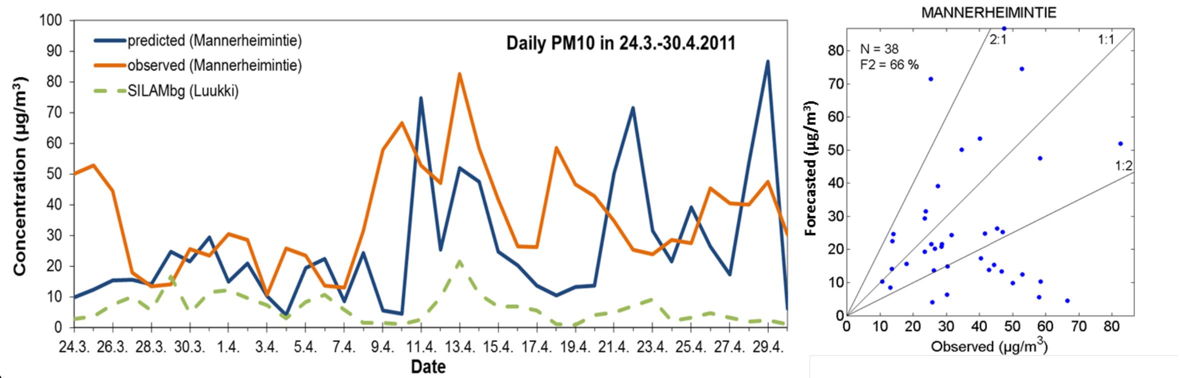
Figure 1. Forecastedhourly average PM_{10} concentrations (µgm^{-3}) on 11 April 2011(at 16local time) in the Helsinki metropolitan area.

The performance of the local air quality forecast system was shortly evaluated by studying forecasted(6 hour forecast) PM_{10} concentrations against observed data at Vallila, Mannerheimintie, and Leppävaara. In order to study the spring dust episodes, the study period was from 24 March to 30 April 2011.Comparison of forecastedand observed daily average PM_{10} concentrations at Vallila, Mannerheimintie, and Leppävaara are presented in Figures 2a-c, respectively, anda summary of the statistical analysis is presented in Table 1.

The local air quality forecast system reproduces the daily variability of the PM_{10} concentrations fairly well. The majority (68 % at Vallila, 66% at Mannerheimintie, and 57% at Leppävaara) of the forecasted daily PM_{10} concentrations are within a factor-of-two (F2) of the measured values. However, negative fractional bias (FB) values -0.35, -0.34, and -0.12 at Vallila, Mannerheimintie, and Leppävaara, respectively, indicate that concentrations are under-predicted in all three locations.



a)



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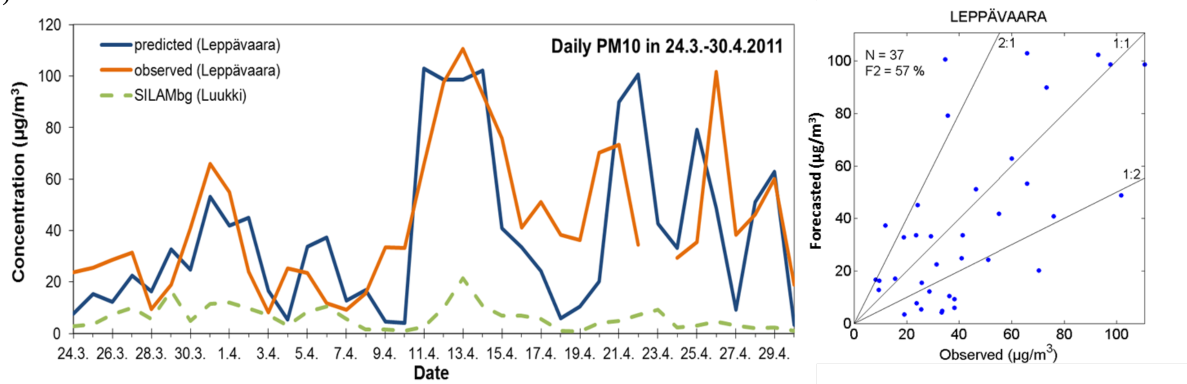

c)

Figure 2.Comparison of forecasted and observed daily average PM_{10} concentrations (μgm^{-3}) at (a) Vallila, (b) Mannerheimintie, and (c) Leppävaara in 24.3.-30.4.2011. The daily average background PM_{10} concentration at Luukki (corrected SILAM forecast) is shown with dotted green line. N is the number of data points and F2 is the fraction of predictions within a factor-of-two of the measurements.

The system seems to work better at Vallila and Leppävaara than at Mannerheimintie; for example, the index of agreement (IA) for the daily PM_{10} was 0.76 at Vallila and 0.80 at Leppävaara, but only 0.53 at Mannerheimintie.The corresponding IA values for the hourly PM_{10} concentrations were 0.54 at Vallila, 0.60 at Leppävaara, and 0.35 at Mannerheimintie. As expected, the IA values are better for daily concentrations, compared with the corresponding hourly values, due to the averaging out of short-term variations.

Table 1.The statistical analysis of the forecasted (Cf) and observed (Co) daily and hourly PM_{10} concentrations at Vallila, Mannerheimintie, and Leppävaara in 24.3.-30.4.2011. The forecasted* daily and hourly average background PM_{10} concentration at Luukki are both 6.17 μgm^{-3}. IA is the index of agreement, F2 is the fraction of predictions within a factor-of-two of the observations, R^2 is the squared correlation coefficient, FB is the fractional bias, and N is the number of cases.

	Daily data			Hourly data		
	Vallila	Mannerheimintie	Leppävaara	Vallila	Mannerheimintie	Leppävaara
IA	0.76	0.53	0.80	0.54	0.35	0.60
F2 (%)	68	66	57	47	47	40
R^2	0.44	0.04	0.44	0.12	0.04	0.16
FB	-0.35	-0.34	-0.12	-0.34	-0.33	-0.11
AvgCf ($\mu g\ m^{-3}$)	18.8	25.7	38.4	18.9	25.8	38.7
Avg Co (μgm^{-3})	26.7	36.1	43.3	26.8	36.1	43.1
N	38	38	37	906	909	835

*) Corrected SILAM forecast.

The results were generally better at Vallila and Leppävaara than at Mannerheimintie. Somewhat worse results at Mannerheimintie compared to two other locations may derive from different traffic and street conditions. According to Malkki et al.(2011) average weekday traffic volumewas 13000 veh day^{-1} at Hämeentie (Vallila), 20200 veh day^{-1} at Mannerheimintie, and 74900 veh day^{-1} atKehä I (Leppävaara).At Vallila and Leppävaara, traffic flows more smoothly with higher driving speedthan at Mannerheimintie, where the street section right next to the monitoring station is usually well congested, deriving low travel speed and unsmooth driving. Unsmooth driving, i.e., accelerations and declarationsare difficult to model and therefore those have not been considered in the emission model of CAR-FMI (Härkönen, 2002). In addition, the present version of the suspension model does not consider different vehicle categories and speed (Kauhaniemi et al., 2011; Omstedt et al., 2005).

The different pavement type can also explain the slightly worse resultsat Mannerheimintie, where roadis paved with stone-blocks, but at Vallila and Leppävaararoads have asphalt pavement. According to Tervahattu et al., (2007) the average summertime dust emission (SNIFFER concentration) was about two times higher in the stone-block paved section of Mannerheimintie compared to streets with asphalt pavement. The present model version cannot account for different pavement types.

The results in this study are slightly worse than those in Kauhaniemi et al., (2011) were the same suspension emission model combined with the OSPM model was evaluatedagainst observed PM_{10} concentrations in Runeberg Street during 8 Jan - 2 May 2004. PM_{10} concentrations were predicted by using observed meteorological and background concentration data. The IA values for the daily and hourly PM_{10} concentrations in Runeberg Street were 0.87and 0.83, respectively.

Obviously more uncertainties are involved when forecasted meteorological and background concentration data are used. The meteorological data used in the air quality forecast system is forecasted by theHIRLAM to the weather station of Helsinki-Vantaa airport that locates about 15 km north of the centre of Helsinki.The short comparison of forecasted and observed meteorological data at Helsinki-Vantaa showed that temperature and wind speed are forecasted fairly well (IA values; 0.92 and 0.89, respectively). However, precipitation and relative humidity, which are important parameters when modelling PM_{10}, did not agree so well with observations as IA values were 0.63 and 0.60, respectively.Temperature and wind speed were under-predicted (FB values; -0.55 and -0.19), whereas precipitation and relative humidity wereboth over-predicted (FB values; 0.56 and 0.29, respectively). The difference in forecasted and observed wind direction is less than 20 degrees in 62% of the cases, and 80% of the wind direction data are within 40 degrees of the observed direction.

The weather conditions can differ significantly, especially when considering precipitation, in within short distances. Thus, the data used in the air quality forecasting can be completely different as situation at the studied location. In Figure 3a and b, forecasted hourly average values of precipitation and relative humidity data are compared to those observed at Helsinki-Vantaa and Kaisaniemi. Kaisaniemi station is situated at the centre of the Helsinki, and therefore it might represent better the weather conditions at Vallila and Mannerheimintie compared to the station at the Helsinki-Vantaa airport.

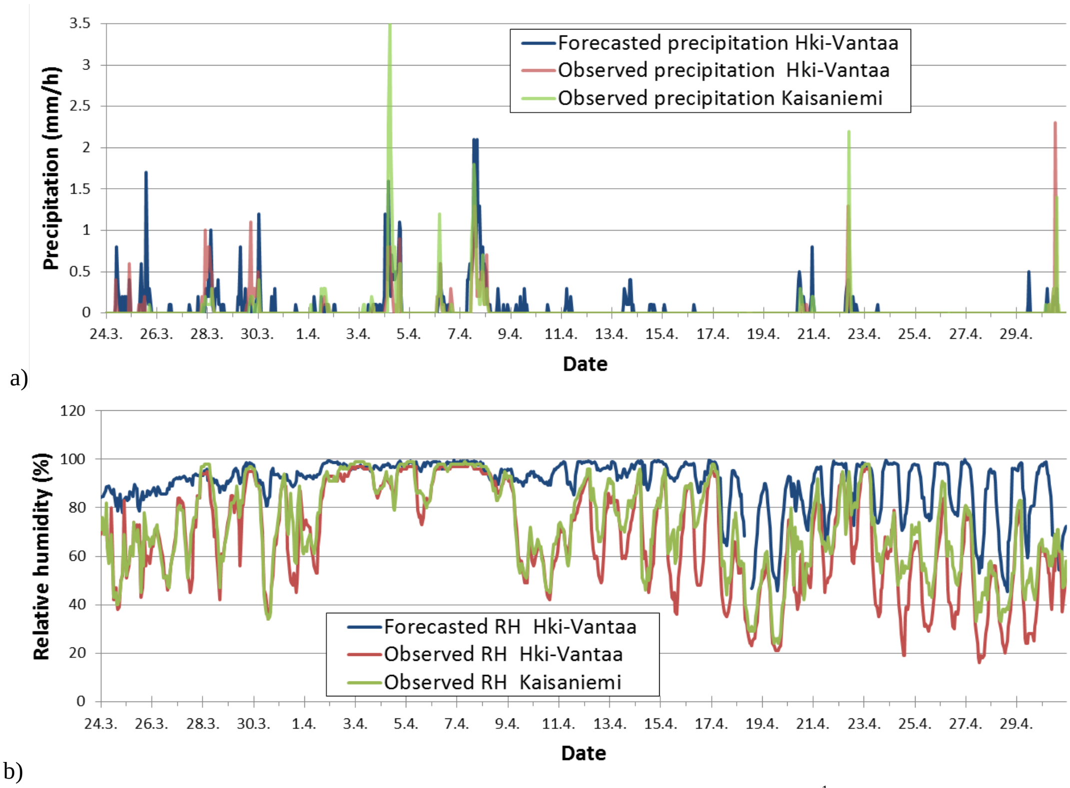

Figure 3. Comparison of forecasted and observed hourly average values of (a)precipitation (mm h^{-1}) and (b) relative humidity (%), at Helsinki-Vantaa and Kaisaniemiin 24.3.-30.4.2011.

CONCLUSIONS

We have presented the local air quality forecast system that utilises meteorological and regional air quality forecasting, urban and regional air quality measurements, and traffic data. The dispersion of pollutant is modelled by the CAR-FMI.The system provides 44 hours forecasts four times a day for the main air pollutants. Concentrations are computed into a grid covering the Helsinki metropolitan area.

Thelocal air quality forecast system wasevaluated against observed data measured in three locations (Vallila, Leppävaara, and Mannerheimintie) inHelsinki from 24March to 30April in 2004.The results show that the system canfairly wellpredict the daily variation of the PM_{10}concentrations, althoughconcentrations were under-predicted in all three locations. The system seems to work better at Vallila and Leppävaarawhere, e.g., thehourly IA valueswere0.76 and 0.80, respectively.The slightly worse results at Mannerheimintie (e.g., IA=0.53) can derive from different street and traffic conditions. Different kind of street pavements, as well as,unsmooth driving conditions cannot be taken into account in the present version of the modelling system.Furthermore, vehicle type and travel speed dependence are excluded from the PM_{10} emission modelling.

The success of the air quality forecasting is also greatly dependent on the forecasted meteorologicaland background concentration data. The forecasted meteorological data from the HIRLAM model was found to agree fairly well with the observed data at Helsinki-Vantaa airport, in case of temperature, wind speed, and wind direction. However, the agreement was worse in case of precipitation and relative humidity, which are the key parameters when considering PM_{10} modelling. In addition, moreuncertainties may be caused as the meteorological forecasts are conducted only for the one sitethat locates far from the studyareas. This can be significant especially in case of precipitation and relative humidity.

Further development is needed especially in case of non-exhaust emission modelling. The performance of the suspension emission model needs to be improved, e.g., by taking into account the output of the Road Weather Model. Further studying is also needed to include, e.g.,vehicle type, speed and road pavement dependence in the suspension emissions, and influence of accelerations and declarations into the traffic emission model.In the future, the system could also be extended with the tool, which computes different statistical values e.g., values comparable to the EU limit values and air quality indexes of the forecasted and monitored air quality data.

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