

Weather monitoring and urban air quality



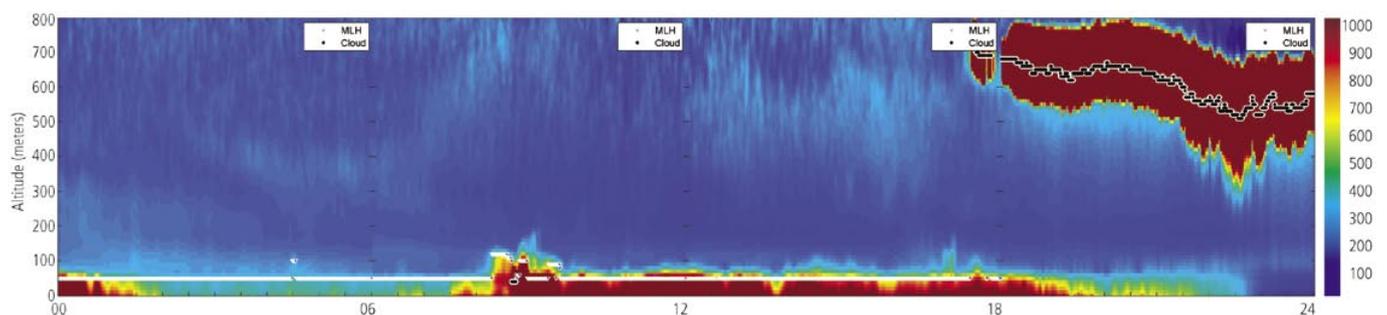
Frequently asked questions

1. How can air pollutants affect human health?
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Urban air pollution poses a significant threat to human health, the environment and the quality of life of millions of people.

Growth in industrialization and traffic has resulted in the increase of air pollution, causing deterioration in air quality. The greatest factor affecting the changes in air quality are changes in day-to-day weather,

as weather determines how quickly pollutants are dispersed away from an area. Weather also determines the thickness of the atmospheric layer, where the emissions are diluted in a vertical direction.



The picture shows a 1-day measurement of aerosol profile using a ceilometer on November 22, 2005 in the Helsinki area, Finland. During the day there was a strong inversion that lasted almost the whole day. A high concentration of low level aerosols (particulates from traffic) can be seen below 100 m, increasing rapidly after 7:30 in the morning.

Measuring and forecasting atmospheric conditions is critical for understanding the formation, transformation, dispersion, transport, and removal of the pollutants. Being able to make good overall estimates - identification of sources, effects on mixing, transformation and transportation - helps to control air quality and implement preventive actions to reduce emissions.

Urbanization and the associated growth in industrialization and traffic have resulted in the increase of air pollution in densely populated areas, causing deterioration in air quality. Many of the world's largest cities - such as New Delhi, Hong Kong, Los Angeles, Mexico City – find themselves in a situation where they need to take action to enhance their institutional and technical capabilities to monitor and control air quality and implement preventive actions in order to reduce the risks that air pollution poses to their citizens.

On the other hand, such countries still face the problem of polluted air

even though air quality has been improving gradually over the last two decades. For example, many large cities in Europe still exceed the specific air quality standards for ambient pollutants. The Helsinki metropolitan area in Finland, for example, is one of the cleanest cities in Europe but still the daily limits are exceeded every year.

1. How can air pollutants affect human health?

A number of epidemiological studies have shown that ambient air pollutants, especially fine and ultra fine particulates, have an adverse effect on human health. This is due to the fact that these tiny particulates can penetrate deep into the lungs and even be dissolved in the blood. The health effects can be especially hazardous for sensitive groups, like children, senior citizens, and people with asthma, obstructive lung disease (chronic obstructive pulmonary disease – COPD), and cardiovascular diseases.

According to the World Bank, every year an estimated 800,000 people

die prematurely from lung cancer, cardiovascular and respiratory diseases caused by outdoor air pollution. In Hong Kong, for example, it is estimated that by improving the air quality from the existing “average” level to “good” level, 64,000 hospital days would be saved.

These severe health effects are the reason that most countries have already taken preventative measures to limit emissions and set limits (called standards) for urban air pollutants. City authorities focus on efforts to reduce emissions and monitor levels of air pollutants.

2. What are the main pollutants in urban air?

Scientists have defined the main air pollutants that pose a health risk for humans in urban areas. These pollutants are: inhalable particulates (PM10) and fine particulates (PM2.5), nitrogen oxides (NO_x), sulphur dioxide (SO₂), ozone (O₃), carbon monoxide (CO), and lead (Pb). For each of these pollutants, the World Health Organization has defined air quality guidelines for protection against harmful health effects. The guidelines define the specific limits or concentrations that should not be exceeded. Countries often have their own standards that are similar but the specific levels can vary slightly.

To measure air quality, networks of monitors record the concentrations of the major pollutants at more than 3,000 locations in the world each day, mostly in developed countries. These raw measurements are then converted into Air Quality Index (AQI) values. The AQI has been developed to make it easier for people to understand the significance of monitored and forecast air pollution levels. It focuses on health effects that can

Particulate Matter (PM) can be divided into four size classes

Class	Description	Size (in diameter)
Large particulates		over 10 microns (>10 μm)
PM10	Particulates that can be inhaled below the nasopharynx area (nose and mouth) and are thus called inhalable particulates	under 10 microns (0 - 10 μm)
PM2.5	Fine particulates that travel down below the tracheobronchial region (into the lungs)	under 2.5 microns (0 - 2.5 μm)
UFP	Ultra fine particulates that can travel in the deepest parts of lungs and be dissolved into blood	0.1 microns (0 - 0.1 μm)
The most hazardous size classes to humans are PM2.5 and UFP as they penetrate into the lungs and can even be dissolved into the blood.		

take place within a few hours or days after breathing polluted air.

An AQI value is calculated for each of the individual pollutants in an area (ground-level particulate matter, carbon monoxide, sulfur dioxide, nitrogen dioxide, and ozone). The pollutant with the highest AQI is used as the overall AQI reading for that day and is listed as the principal pollutant.

301 - 500	Hazardous	Maroon
201 - 300	Very unhealthy	Purple
151 - 200	Unhealthy	Red
101 - 150	Unhealthy for sensitive groups	Orange
51 - 100	Moderate	Yellow
0 - 50	Good	Green

3. What are the main sources of emission?

Most air pollution comes from human activities: burning either fossil fuels (coal, oil or natural gas) to power motor vehicles and industrial processes, or burning of biomass to heat houses or produce energy. The burning processes release particulate matter, carbon monoxide, carbon dioxide (CO₂) and partially burnt hydrocarbon compounds into the atmosphere. Depending on the origin of the fuel, SO₂ concentrations released in combustion vary considerably. Technologies to remove it in energy production are available and already in common use in most developed countries. Carbon dioxide, however, is not counted as a pollutant but the main greenhouse gas.

Pollution from traffic consists of particulate matter, NO_x, CO, Volatile Organic Compounds (VOCs), and also other compounds in

Various agencies around the world measure such indices, though definitions may vary. The index is defined so that it gives a value of 100 at the specific value of each pollutant. The United States Environmental Protection Agency (EPA) has determined the AQI scale and health classification as:

small amounts, like polyaromatic hydrocarbons (PAH). Lead emission from traffic has reduced dramatically after moving to unleaded fuels. Particulates come from the exhaust emissions, especially from diesel engines, but also from dust and dirt from roads and tires. Other fine particulates are formed by chemical reactions in the atmosphere. Formation of ozone (O₃) in urban areas is mainly caused by traffic pollutants in a photochemical reaction with UV radiation from the sun.

Some of the pollutants also come from natural sources. For example, forest fires emit particulates and VOCs into the atmosphere. Volcanoes spew out sulfur dioxide and large amounts of volcanic ash. Sand storms can also mix particulates into the air from the underlying ground surface. Vegetation emits VOCs that are different from those formed in burning processes.

4. How does weather affect air quality?

Changes in day-to-day weather are the greatest factor in controlling the changes in air quality. Weather determines how quickly pollutants are dispersed away from an area and also the thickness of the atmospheric layer (called the mixing height) where the emissions are diluted in a vertical direction. Normally, pollutants are mixed with the help of convection or blown away by wind from their sources without building up to unsafe amounts.

But the pollutants can also be trapped close to the surface. They cannot escape, and after a while they may build up to unhealthy levels. This trapping can happen when winds are weak or calm, and when the air close to the ground cools down and warm air moves over, creating a stable condition that keeps pollutants close to the surface. These so-called inversions frequently occur on clear nights.

Poor air quality can also result from summer heat. In hot, sunny weather photochemical smog can form through complex chemical reactions involving NO_x, O₃ and VOCs. Photochemical smog has a light brown color and can reduce visibility and affect breathing.

Wind can also transport pollution over long distances. For example, in the Helsinki metropolitan area, more than half of the fine particulates (PM_{2.5}) are transported from outside the country, mainly from Central and Eastern Europe.

Air pollutions are finally washed out of the sky by rain, fog or snow. This is called "wet deposition".

When air pollutions deposit without the benefit of rain, it is called "dry deposition".



When winds are weak or calm, and when the air close to the ground cools down and warm air moves over, a stable condition can be created that keeps pollutants trapped close to the surface. These so-called inversions frequently occur on clear nights.

5. How can air quality be estimated and forecast?

Air quality can today be forecast for a few days based on the weather forecast and a corresponding “chemical transport” model. Unfortunately the normal weather forecasts do not fully serve the needs of air quality forecasting. Measuring and forecasting atmospheric conditions is critical for understanding the formation, transformation, dispersion, transport, and removal of the pollutants. More specific data on atmospheric conditions is needed for better forecasts. One of the tasks is to get more dense and accurate observation data on the mixing height across urban areas to better determine the air volume where the surface pollutants are mixed. Modern air quality models can take a variety of data as input: inventory

and models of emission sources, local dispersion and mixing, weather model and forecast, long-range transportation of pollution, chemical reactions and deposition.

The major needs for atmospheric weather parameters for air quality forecasting include both surface and vertical profile measurements. The main parameters are wind speed and direction, turbulence, vertical wind and temperature profiles (to determine the layered atmospheric air structure), visibility, cloud height and cover, rain, and solar radiation.

6. How can weather be measured?

Radiosondes, boundary layer profilers, ceilometers, wind sensors as well as surface weather sensors and stations are among the technologies used for measuring atmospheric weather conditions

relevant to the air quality estimation, dispersion and forecasting.

Radio soundings form the backbone of atmospheric profile data the world over. Radiosondes are meteorological devices that are used to measure temperature, humidity, pressure, and wind speed and direction. The World Meteorological Organization’s Global Observing System network releases more than 1,400 radiosondes every day, taking measurements from the earth’s surface up to altitudes of about 30 kilometers in the upper atmosphere. More specific sensor options make it possible to measure also ozone and radioactivity profiles.

A boundary layer profiler uses radio frequency (RF) Doppler technique to provide continuous data on wind speed and direction at different altitudes up to several kilometers. With an optional acoustic system (Radio Acoustic Sounding System, RASS), it can also measure the virtual temperature profile that can be used to determine stability conditions. The RF signal (intensity and spectrum) can also be used to determine the mixing height as turbulent structure at the top of the mixed layer provides higher reflectivity and a broader spectrum for the RF signal.

Measurements near the surface level are also essential to estimate, for example, mixing and transport of surface emissions. Meteorological instruments measure the principal weather parameters, like wind, temperature, humidity, pressure and rain. In some areas, visibility is used as an indicator for the air quality.

Ceilometers are designed for the measurement of cloud height and cover utilizing optical lidar technique (light detection and ranging).

These devices, however, have also turned out to be outstanding for air quality measurement purposes due to the principle of measurement. They measure optical scattering of aerosols and ice crystals to see the clouds. As the performance and sensitivity has increased over the years, they can also measure the low levels of pollutant aerosols – particulate matter. This can be used to determine the real profile and mixing height of the aerosols. Ceilometers have been successfully

used for this purpose to provide important continuous data on the hour-to-hour and day-to-day variation of the aerosol profile.

Vaisala has built a dense observation network in the Helsinki metropolitan area in collaboration with the Finnish Meteorological Institute to serve the purpose of air quality measurement, among other applications. This Helsinki Testbed observation network is based on a number of mast measurements using weather transmitters at several altitudes. In

addition to wind profile information near the surface, the vertical mixing conditions of the atmosphere can also be calculated from the vertical temperature gradient.

The dense network also includes five ceilometers that measure the aerosol profile and mixing height. The aim is to use this data set for air quality modeling to improve the real-time estimation and forecasting of spatial and temporal variations in air quality.



7. What to do with the air quality information and forecasts?

Air quality agencies and national meteorological institutes use real-time observation instruments and systems to improve their estimations, forecasts and warnings on air quality for decision-makers

and the public. The most important users of air quality information are the sensitive groups who need the information to avoid bad outdoor air and to be able to take precautions in advance.

Good overall estimates of urban air pollution - identification of sources, effects on mixing, transformation

and transportation – help in making decisions to control air quality and implement preventive actions to reduce emissions. The choices we make every day, about how to get to work, how to heat our homes, and what to consume, for example, all influence air quality in our region.

Candidate meteorological observing systems for dispersion applications

Dispersion variables	Meteorological variables (not all required; algorithm dependent)	Candidate measurement systems
Transport	Three-dimensional fields of wind speed and wind direction	Profilers; Doppler weather radar; RAOBs; air-raft; tethersonde; Doppler lidar
Diffusion	Turbulence; wind speed variance; wind direction variance; stability; lapse rate; mixing height; surface roughness	3D sonic anemometers; cup & vane anemometers; RAOBs; profilers; RASS; scanning micro-wave radiometer (maybe); tethersonde
Stability	Temperature gradient; heat flux; cloud cover; insolation or net radiation	Towers; ceilometers; profiler/RASS; RAOBs; aircraft; tethersonde; net radiometers; pyranometers; pyrgometers
Deposition, wet	Precipitation rate; phase; size distribution	Weather radar (polarimetric); cloud radar; profilers
Deposition, dry	Turbulence; surface roughness	See turbulence
Plume rise	Wind speed; temperature profile; mixing height; stability	Profilers/RASS; RAOBs; lidar; ceilometer; tethersonde; aircraft

RAOB – rawinsonde observation

RASS – radio acoustic sounding system

Source: Advances in meteorological instrumentation for air quality and emergency response, W.F.Dabberdt, G.L.Frederick, R.M.Hardesty, W-C.Lee, and K.Underwood. Meteorology and Atmospheric Physics (2004).



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