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Air Quality Monitoring Systems and Application

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1. Introduction

Development of technical monitors and telemetric systems have made environmental data more readily available to planners, authorities and to the public. In line with awareness and the strong focus on our environment the modern environmental monitoring and surveillance systems have also become information systems that can provide relevant information at different levels about the state of the environment, quickly and precisely.

The integrated approach towards environmental management is based on the view that the environment should be monitored and followed as an entity. This is also in line with the concept "sustainable development" introduced by the Brundtland Commission, and which has been widely adopted by both national governments and international organizations.

Today's environmental information systems combine the latest sensor and monitor technologies with data transfer, data base developments, quality assurance, statistical and numerical models and advanced computer platforms for processing, distribution and presenting data and model results. Geographical Information Systems (GIS) are an important tool, particular for the presentation of data.

These technologies can be used in environmental management to support integrated pollution prevention and control. They can also be part of an emergency management system to support actions and crisis management during emergencies and accidents of various kinds. The content and operability of the system might be quite different in the two cases. In the following we will describe the content of a surveillance system for local and regional environmental management, for urban areas or regions dealing with industrial problems, traffic, energy sources and solid and liquid waste.

Most of the examples below are related to the development of a system for air pollution monitoring and information. The examples given mostly apply to air quality studies in urban areas. However, the descriptions can also very well be applied to other types of environmental issues. Biological monitors or direct impact monitoring (on man and the environment) is not covered by the described system.

2. A modern environmental monitoring and information system

2.1 The technical features of the system

The key features of the modern environmental information system is the integrated approach that enables the user in a user friendly way to not only access data quickly, but also use the data directly in the assessment and in the planning of actions. The demand of the integrated system to enable monitoring, forecasting and warning of pollution situations has been and will be increasing in the future. The data may also be used for generating new indicators that relate directly to health impacts. This will require that numerical dispersion models for air pollutants are available with on-line data input as a part of the system in urban areas.

Several systems are currently being developed and have been demonstrated in selected areas in Europe. One such system, "ENSIS '94", an ENvironmental Surveillance and Information System, was developed as part of the Eureka project for the Winter Olympic Games in Lillehammer. (Sivertsen and Haagenrud, 1994). The following description is based on this prototype.

The ENSIS concept has later been developed further into an AirQUIS module for air pollution surveillance, a WaterQUIS module for water pollution, and similar modules for noise, deterioration of materials and buildings etc. The different modules are all operated under the same main framework and can be combined in a flexible total system.

Other integrated systems are being established in Europe. One of the important topics of the European Commission DG XIII Telecommunications, Information Market and Exploitation of Research, Telematics Application Programme (1994-1998) deals with this subject. Several major urban areas in Europe will thus be involved in the establishment and demonstration of such systems.

The main features of the integrated surveillance and information system for the environment is shown in Figure 1.

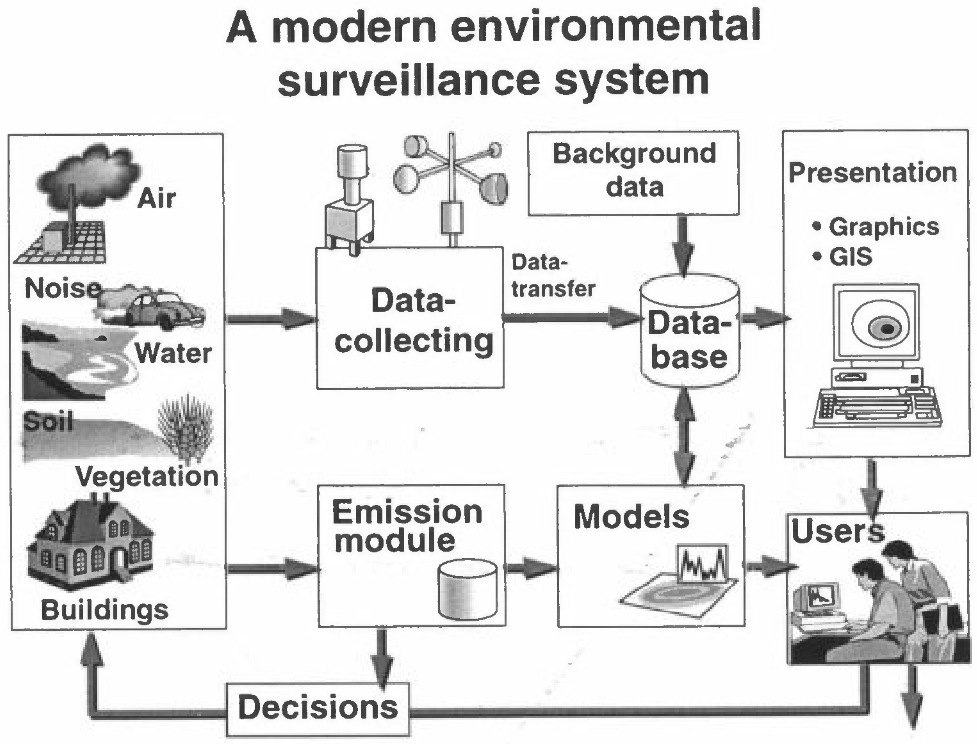


Figure 1: The principal structure of a modern environmental monitoring and information system.

An important objective for the modern environmental surveillance platform is to enable on-line data and information transfer with direct quality control of the collected data. This may require new sensor technology or modification of present monitoring methods. Several monitors and sensors that makes on-line data transfer and control possible are already available on the market. For several other compounds and indicators this is not the case.

The system should include:

- Data collectors; sensors and monitors,
- data transfer systems and data quality assurance/control procedures,
- data bases included emission and discharge modules,
- statistical and numerical models (included air pollution dispersion models and meteorological forecast procedures),
- user friendly graphical presentation systems including Geographical Information Systems (GIS),
- a decision support system,
- data distribution systems and communication networks for dissemination of results to "outside" users.

The different parts will in the following be described in more detail.

2.2 Sensors and monitors

2.2.1 New instruments needed

Modifications and development of new sensors and monitors are necessary to establish a complete environmental information system that meets the requirements of today's users. Several sensors and monitors for meteorology, noise, air- and water quality are already available on the market. However, not all of these can be linked on-line to a data transmission and data quality control system.

A description of measurement techniques for environmental parameters are presented in later chapters. For air pollutants it is important to decide whether one wants to measure *in situ* to obtain a point measurement or take an integrated sample over a distance or a volume. In the latter case different optical methods using light absorption have been developed and used during the last few years. Specific methods including single line spectroscopy with advanced optical filters or tuneable diode lasers emitting light at one particular wavelength have also been, or are being developed for selected individual air pollutants. However, it is difficult to obtain *in situ* measurements i.e. in streets with these instruments. The cost of these instruments is also high, depending on the number of parameters needed to get a good indication of the status of the air quality. (See indicators.)

A new generation of water quality sensors for process control and water management was demonstrated during the ENSIS programme in Lillehammer 1994. It included the monitoring of drinking water, waste water treatment and river water acidity.

2.2.2 Meteorological data

Meteorological data are important input data to a system that is to be used for information, forecasting and planning purposes. Meteorological data are also important for explanatory reasons together with climatological data. Meteorological data are needed from the ground, normally collected along 10 m towers, and up to the top of the atmospheric boundary layer. Automatic weather stations are currently being used in most large field studies, in remote areas and in complex terrain. Meteorological "surface data" such as winds, temperatures, stability, radiation, turbulence and precipitation are being transferred to a central computer via radio communication, telephone or satellite.

One of the more difficult parameter to obtain on a routine basis is the height of the boundary layer as a function of time. This height is often related to and referred to as the mixing height. When air quality models are being applied for exposure modelling, information and forecasting and decision making purposes, meteorological input data from the boundary layer are crucial.

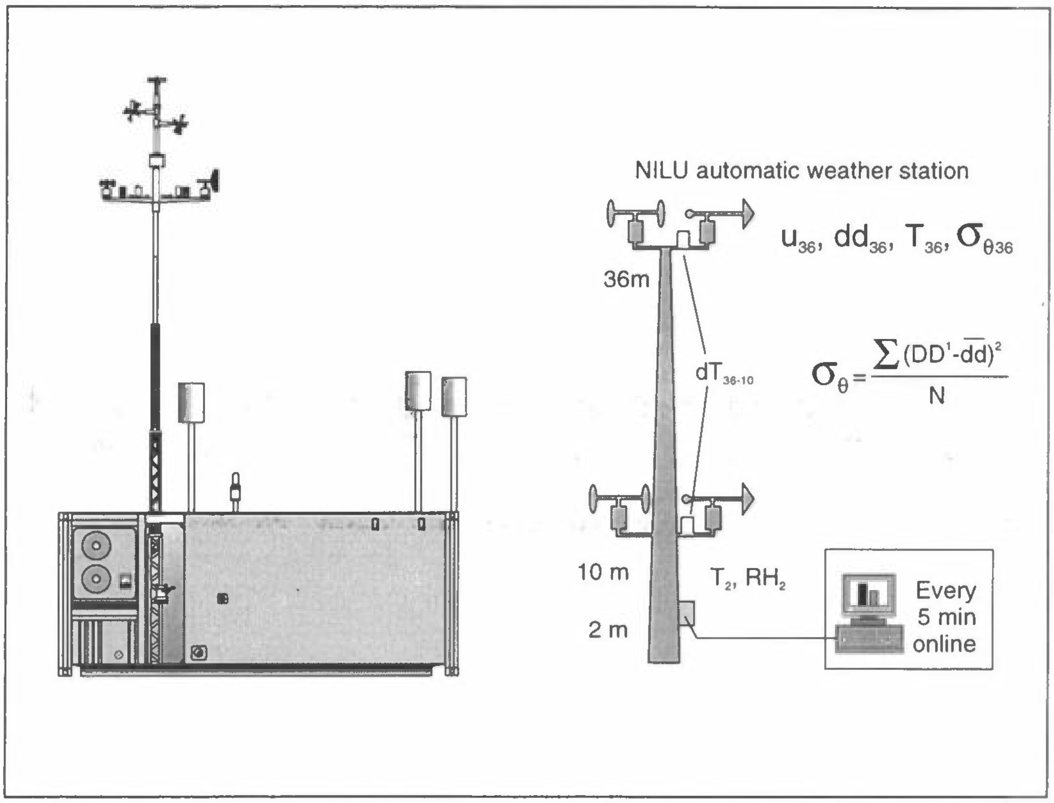


Figure 2: A typical field monitoring station with an Automatic Weather Station (AWS) and meteorological sensors along a 36 m tower.

To improve the meteorological input data for numerical air quality models in urban areas, more advanced three dimensional wind and turbulence measurement equipment should be included. These instruments can measure the atmospheric turbulence directly. These turbulence data can be used directly to estimate the dispersion more accurately. Many areas have already installed Doppler sodar systems that can measure the vertical structure of wind and turbulence. These data are also subject to certain ambiguities, but represent a valuable additional input to the models for on-line information and warning.

A combination of measurement data (at several locations) and model estimated wind fields will represent the necessary input to numerical air pollution dispersion models in a complex urban area. These models are usually set to estimate concentration distributions on an hourly basis, and the most important parameters are therefore the flow pattern and a correct picture of the transport of pollutants. In some cases, especially when applying mesoscale and regional scale models, remote sensing of weather systems from satellites may prove a useful tool for estimating input data.

2.3 Environmental indicators

The selection of parameters included in the monitoring and model estimate programme should enable an automatic access to data relevant for assessing the environment included air pollution and atmospheric conditions, pollution of rivers and seas, ground water, waste, noise and radiation. For all these environmental compartments there should be a set of environmental indicators.

These indicators should represent a set of parameters selected to reflect the status of the environment. An indicator may be a single variable of sufficient sensitivity to reflect changes in the status of the environment. In some cases, however, indicators may be derived from a set of independent variables in the system. The selection of indicators should also allow evaluation of trends and developments. The aim is that the indicators can form a basis for evaluating the impact on humans and the environment as a whole and thereby be relevant for information, warning and decision making purposes.

Many national and international authorities are presently working with processes to select environmental indicators. The result of this work will not be available in another few years. In the meantime, for air quality, the selected parameters are mostly related to air pollutants for which air quality guideline values are available.

The development of environmental indicators in Europe will contribute to the harmonization of several initiatives. This activity will be important input to the design and content of monitoring programmes. Harmonization is an important concept both in monitoring and in modelling. It allows different methods to be used to measure the same variable to predetermined levels of accuracy and precision. Even if different methods are applied the data from each location can be comparable and compatible.

The selected set of environmental indicators will be used by local and regional authorities as a basis for the design of measurement programmes and for reporting the state of the environment.

The establishment of environmental indicators will help to:

- identify the quality of the environment,
- quantify the impact,
- harmonize data collection,
- assess the status and the rate of improvement/deterioration,
- identify needs for and support the design of control strategies,
- support input to management and policy changes.

The indicator should represent the "pressure" on the environment and include both background indicators and stress indicators. So-called response indicators are selected to reflect the societies awareness or response to its surroundings.

The indicator should:

- be relevant in connection with environmental quality,
- be easy to interpret,
- respond to changes,
- provide international comparisons,
- have a target or threshold value that provides a basis for assessment,
- be able to show trends over time.

It should also be possible to measure with reasonable accuracy. It should be adequately documented and linked to public awareness; health impact, building deterioration, vegetation damage etc. Selected indicators should respond to mitigation actions to prevent human made negative impacts on the environment.

Indicators might also be aggregated data and not necessarily observed single parameters. The modern environmental surveillance and information systems (ENSIS) include good quality on-line meteorological data, numerical dispersion models with emission inventories. These models are capable of estimating concentration distributions on an hourly basis. These distributions can be linked to population distribution maps, building material inventories, vegetation maps etc. to give exposure estimates.

These aggregated, estimated data will express directly the impact and stress to the environment (health, materials, vegetation) and will in the future represent a better indicator for international comparisons and trend analyses. It will also represent an improved measure for the actual air pollution problem in a given (well defined) area or region.

2.4 Data transfer and quality assurance

Specially designed data loggers for environmental data are available. Data loggers designed and built by NILU were included in the ENSIS '94 application. The logger should be robust and serve as a local backup storage unit in case of link brake down (lightening, storms etc.). The logger is directly linked to a modem.

Data transfer can be via local radio communication for limited distances. This has been the case for a distributed local net of several meteorological stations where data are transmitted via radio link to the main station in the area. Data will further be transmitted on public telephone lines or via satellite to the main computer facility. The central unit might be a major field station or a central laboratory. For an emergency system developed for the Eureka project MEMbrain, a field laboratory has been established with a work station computer including all modelling tools. (Sivertsen, 1994b)

Data quality assurance programmes including direct quality control is performed at different levels in the data collection process;

- in field during automatic and manual calibrations and controls,
- at the central data collection base following quality assurance routines as described i.e. in ISO 45001 from the International Standardization Organization,
- in approvals to the final data base,
- through simple statistical and graphical evaluations to check validity and representativeness of data.

The quality control procedures give the data credibility. The data become reliable, which is essential when using the data for reporting, controls and planning. To be used with confidence for scientific and environmental management purposes the data must also be comparable and compatible.

Integrated data from local sites and from various environmental compartments require comparable data quality. The various local networks have to operate to high standard including proper implementation of good practice by network managers and site responsible personnel.

2.5 The data bases

The development of an associated data base or metadata is important to all modern environmental monitoring and information systems. The data base system

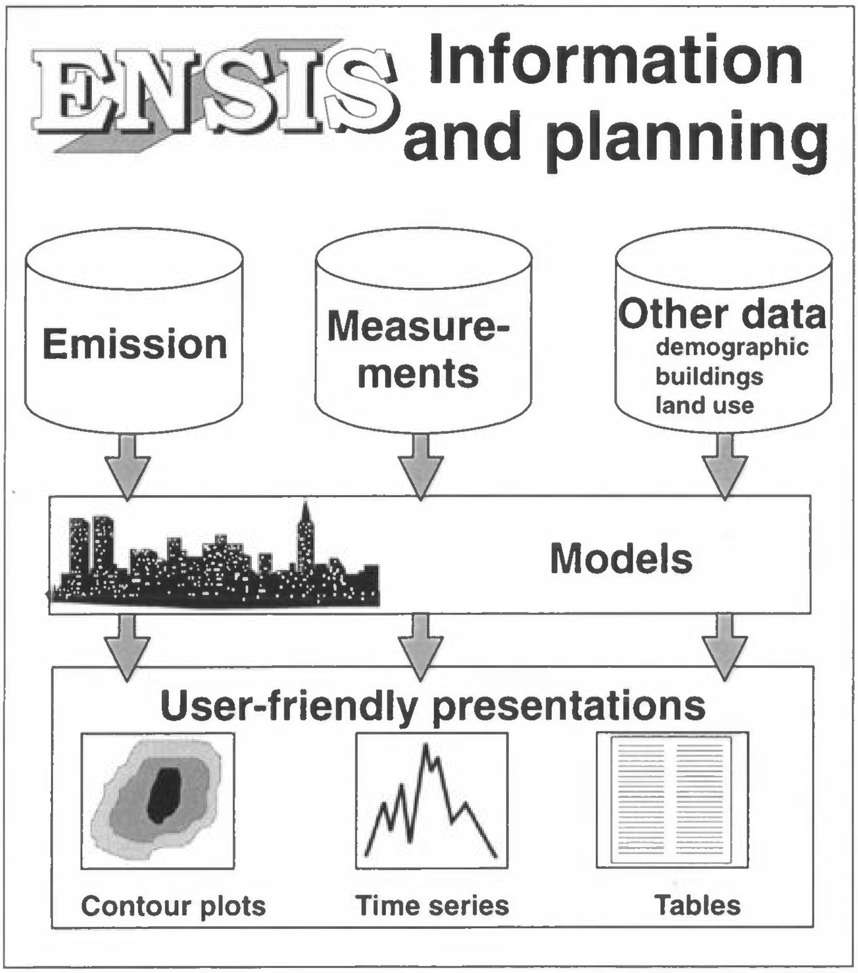


Figure 3: The associated data bases are linked to a modelling system which provides user friendly presentations of all kinds of information from the system.

may consist of several data bases which serve as main storage platforms for:

- on-line collected environmental data,
- emission and discharge data included emission modelling procedures,
- historical data and background information like area use, population distributions and trends,
- regulations, guideline values and information on the support and decision making process.

The data bases contain information that enables an evaluation of the actual state of the environment and it includes data for establishing trend analyses, warnings and the undertaking of countermeasures in case of episodic high pollution.

2.5.1 The on-line data base

All data collected on-line will after quality assurance and controls be part of the information data base. From this base it will be possible to obtain quick graphical presentations, or to subtract data for public information purposes etc.

2.5.2 The emission data base

The emission data base is an interactive platform for collecting input data for emission estimates. It contains information about the sources, emission factors, consumption data, information on locations (gridded co-ordinates), stack heights, stack parameters, fuels etc. The emission data base can be operated directly by the user, who can use the emission models directly to present emission data directly. Any changes and additions to the emission data base will result in updated emission estimates with links to the dispersion models and resulting database for graphical presentation.

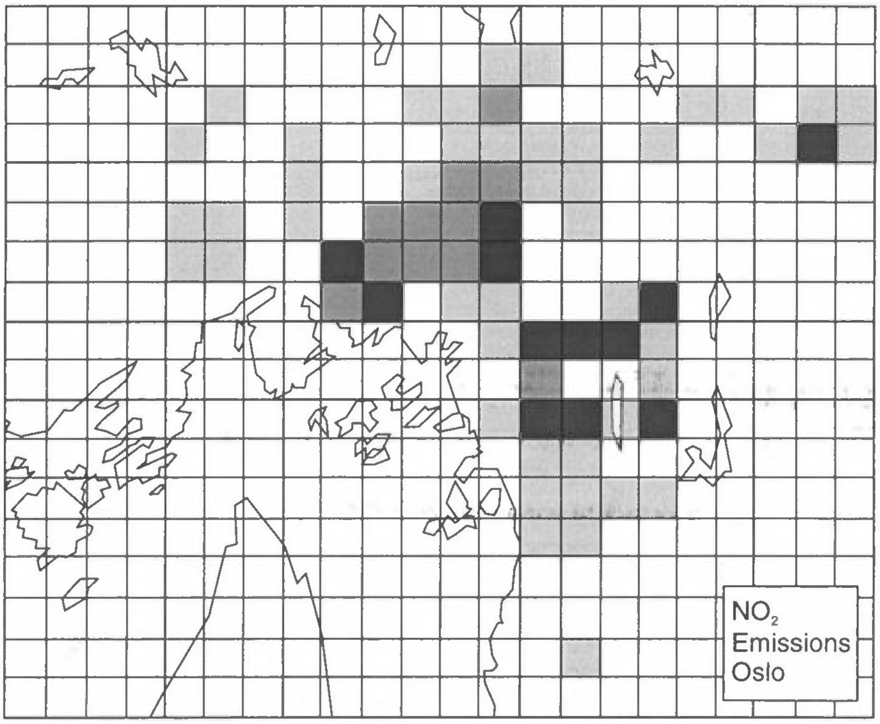


Figure 4: An emission inventory of NO$_x$ emissions presented in a 1×1 km grid for Oslo. The emission estimates have been based upon fuel consumption data, industrial sources, traffic and emission factors.

2.5.3 Historical and background data base

The historical and background data base module includes relevant objects and information such as monitoring stations and sensors, sensor developers, responsible institutions, locations and measurement schedules, methods, data owners, maintenance routines etc. It also contains information about earlier and additional environmental data collected in the area. Background information such as area use, population distributions and inventories of vegetation and materials/buildings in the area may be an important part of this data base. Such information can be used for impact assessment estimates and for some of the emission estimates.

2.5.4 Supporting data base

The supporting data base, which may be part of the background data base contains information on regulations, requirements, air quality guideline values or water quality standards for various applications.

Information about regulations and plans given by local authorities or by governmental bodies should be included in this database, as well as support actions and emergency procedures.

The total associated database system will also serve as a link to a meta information system which includes information on external environmental data. These functions might also include:

- navigation facilities to access the needed information,
- support for standardization activities,
- world wide web/internet functions and bridges.

The data base model is designed to support local and regional levels and meets most of the requirements specified by the users.

Modifications and additions must be easily made in the database. Routines for safety copying and reconstruction must be available. Different data deliveries might be operating in different systems. This requires the establishment of different communication systems with open communication solutions.

2.6 The models

In the modern multi compartment environmental information system (like ENSIS) steps have been taken to establish models for air pollution dispersion, for water quality and noise and for other environmental impact assessment estimates. Models for these media will be essential when the programmes are to be used for planning purposes.

The air pollution dispersion models are a well-established and fully implemented part of the system. These models have been tested and demonstrated as part of the integrated surveillance systems and is presently being operated in several cities on a routine basis. Also water quality modelling is available and is being tested and verified as part of the ENSIS system.

Different types of dispersion models have been developed and applied to estimate the ambient impact of air pollution emissions from point-, line- and area sources. These will be described in more details in ch. 6.

The selection of models to be used in a specific case is dependent upon the spatial and temporal scales, complexity of source configurations and chemistry, topographical features, climate and instationarity/inhomogeneity in the meteorological conditions of the area. It is advisable to consult experts in this process.

A variety of different models are available on the market today. However, one should note that it may be a significant step from obtaining a model to actually having an operable modelling tool for a specific area and application.

Different types of models available are taken from the air pollution surveillance programmes. They range from single quasi stationary Gaussian type single source models based upon analytical solutions of the mass balance equations, to advanced numerical models which require large computers.

The simplest models can be used on personal computers for impact assessment. These models can estimate 1 h average concentration distributions downwind from ground level, diffusive and elevated single sources. (Sivertsen 1980, Bøhler 1987)

One step up represents the short term model for estimating 1 h average concentration distributions for emissions from multiple source industrial complexes (Bøhler 1987). This includes the multiple source Gaussian type models for estimating short term or long term integrated concentrations in a gridded co-ordinate system. Two different type of such models have been developed at NILU; CONDEP for monthly, seasonal and annual average concentration distribution estimates (Bøhler 1987) and KILDER which is a flexible emission inventory linked to multiple source Gaussian type dispersion models for line, area and point sources. (Gram and Bøhler 1992).

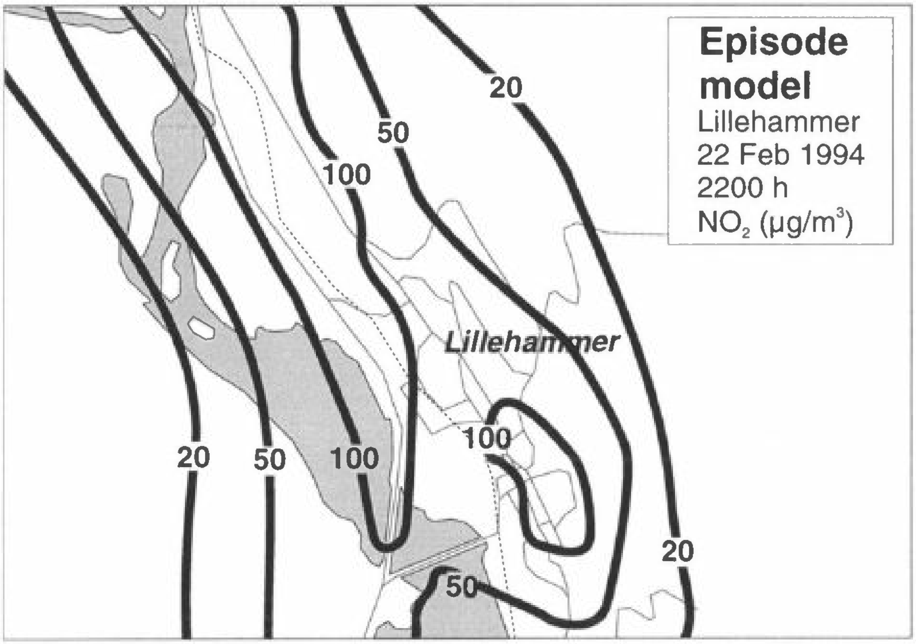


Figure 5: Modelling of one hour average NO_2 concentration distributions from the Lillehammer Winter Olympic programme.

The grid system used by the models is specified by the user to match the specific problem and the area considered. The resolution, grid spacing and total area can easily be modified and changed depending upon the specific needs.

These models need as input data some background information on;

- source characteristics and emission data,
- area characteristics (surface roughness, topography etc.),
- measurement data (measurement type, heights etc.),
- meteorological data (wind, stability, mixing height, temperatures etc.),
- dispersion coefficients (type to be used and parameters),
- dry and wet removal coefficients,
- location of receptor points (distances or grid specifications).

All the NILU models have been well documented and are being used for planning purposes and for impact assessments both nationally and internationally.

Small scale models are also available for estimating the air pollution load from traffic in street canyons and along roads. A commercially available model, ROADAIR (Larssen and Torp, 1993), estimates emissions, concentrations and exposure along the road system based upon traffic data. These input data may originate from traffic models or from traffic density data and on-line traffic counting.

On a spatial scale from about 1 to 100 km there are several types of numerical models available; both Lagrangian type and Eulerian type models. The Lagrangian type models follow puffs of air pollutants estimating in each puff the turbulent diffusion, chemical reactions and deposition processes. The turbulence description and the diffusion processes may be treated in different ways.

One example is the INPUFF model (Knudsen and Hellevik, 1992) which is based upon Gaussian concentration distributions in the puff. This model also includes chemical and physical reactions and processes. Another model of this type is the Danish operational puff diffusion model RIMPUFF (Mikkelsen et al., 1987). This model was developed by Risø National Laboratory to provide risk and safety assessment in connection with e.g. nuclear installations.

One example of an Eulerian type numerical dispersion model is the EPISODE model developed by Grønskei et al. (1993). This is a time-dependent finite difference model normally operating in three vertical levels, combined with a puff trajectory model to account for subgrid effects close to individual sources. When the size of the puffs reaches the horizontal and vertical grid size the transport and dispersion is treated as a numerical box model. The mass of pollutants are then added to the average value for that grid element. The model can thus treat point sources, area/volume sources and line sources. The wind field used as input to the model may be homogeneous or inhomogeneous for each time step dependent upon the meteorological input data available.

For the selection of models to be used in a specific case there have been different methods indicated. Sivertsen (1979) indicated a flow chart for selecting models dependent upon type and complexity of the sources, spatial and temporal scales, chemical composition (secondary or primary pollutants), topographical features, climate and meteorological features of the selected area.

For further information on the use of models, Hanna et al. (1982) give a good overview of the topic. One important issue when using dispersion models is to obtain adequate meteorological input data. Meteorological pre-processors have been developed during the last few years to handle this problem. (Paumier et al., 1985 and Bøhler et al., 1996). These pre-processors can estimate meteorological dispersion and the basic meteorological variables of interest for diffusion modelling based upon the current concepts regarding the structure of an idealized boundary layer. (Gryning et al., 1987). Methods are also provided for estimating the vertical profiles of wind velocity, temperature and the variances of the vertical and lateral wind velocity fluctuations.

2.7 Data presentation; graphics and GIS

Environmental data collected through the automatic monitoring and telematic network will be quality controlled and transferred for storage in the integrated relational databases. Statistical programmes for control of quality and representativeness will be used, and the first results can within one hour after field collection be presented using user-friendly graphical tools.

The information may be multimedia: texts, tables, graphs, images, sound or video dependent on the end user. The presentations have to be designed to meet the user needs. These users may be:

- authorities at different levels (municipal, regional, national, international),
- industrial users,
- schools, universities and the scientific community,
- various organisations,
- the public and media.

The environmental data are usually linked to geographical sites. In particular when monitoring data are supported and supplied by model estimates of spatial concentration distributions and impacts, it is suggested that the presentation of the results would involve the use of maps or digitalized Geographical Information Systems (GIS).

Geographical information systems based on advanced raster/vector technology has been developed to handle maps, networks, symbols and various objects. They can handle both geographical information and technical documentation and present this in graphical form. The basic raw map information has normally been workstation based, but user friendly PC based applications for displaying e.g. environmental data have been developed during the last few years.

The GIS user can easily organise selected data from various data bases. Tematic maps can be produced combined with time series graphical presentations and results from model calculations. The system will display the results of planned actions based upon simulation models and thus act as a more user friendly decision support system.

For the application of ENSIS during the Winter Olympics in 1994 ArcInfo and ArcView were selected as the map reference systems. The GIS tool was directly linked to the data bases, from which statistical evaluations, graphical presentations and spatial distributions from numerical models were presented.

2.8 Environmental information to the public

A wider distribution of environmental data to the public has become a part of the development of modern environmental surveillance and information systems. New approaches have been developed for dissemination of environmental information which can be adapted to different information distribution systems. These systems could be teletext, public telephone network, special designed health advice information lines, telefax distributions, INTERNET networks etc..

Information of air quality in urban areas have been issued to the public on a daily basis described in terms of "very good", "good", "poor" etc. Some European cities already provide this type of information. The modern information system will focus more on variable messages and more updated access to the data through teletext or Internet applications.

As part of the ENSIS development a windows-based PC presentation solution was developed giving multiple access to different databases meeting common graphical user interfaces. It is important that the platform is graphical and preferably MS-Windows or X-Windows operating systems in a client-server network configuration, that can provide access via wide area networks (WAN) to external databases.

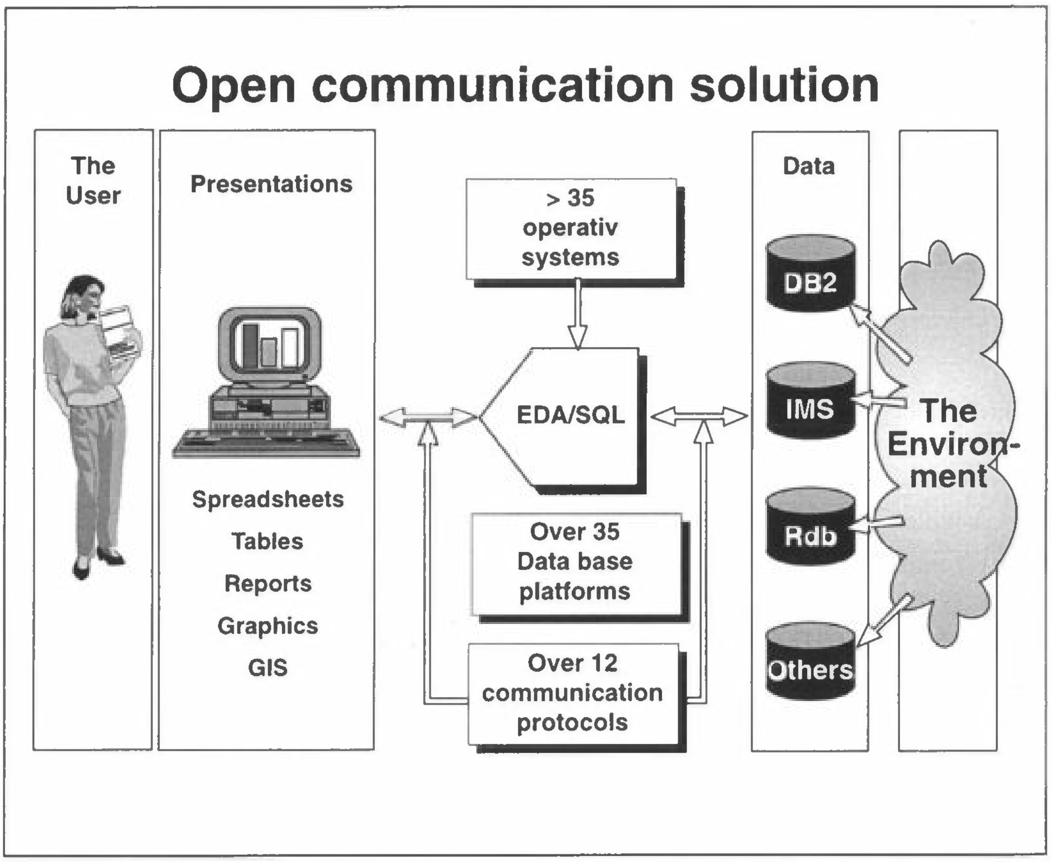


Figure 6: The user oriented open communication solution established during the Eureka ENSIS development project. Any type of data could be accessed and presented through a flexible graphical user interface based on Windows 3.1.

Several local authorities in Norway can presently obtain air quality information in graphical form from several urban areas participating in the national surveillance programme co-ordinated by the Norwegian Pollution Control Authorities. In Oslo and Bergen this system is being used to develop information and forecasts on air quality to the public. Lines have been set up to an information screen available for the public and information is also being issued in the media daily.

3. Air Quality Indicators

It is normally not possible to measure all the air pollutants present in the urban atmosphere. We therefore have to choose some indicators that should represent a set of parameters selected to reflect the status of the environment. They should enable the estimation of trends and development, and should represent the basis for evaluating human and environmental impact. Further, they should be relevant for decision making and they should be sensitive for environmental warning systems.

Many national and international authorities are at present working with processes to select environmental indicators. The selected parameters for air quality are strongly related to air pollutants for which air quality guideline values are available. The interrelationships between the indicators and other related compounds, may, however, vary slightly from region to region due to differences in emission source profiles.

The selected set of environmental indicators are being be used by local and regional authorities as a basis for the design of monitoring and surveillance programmes and for reporting the state of the environment.

Air quality indicators should

- provide a general picture,
- be easy to interpret,
- respond to changes,
- provide international comparisons,
- be able to show trends over time.

Measurement techniques should be reasonably accurate and within an acceptable cost. The effect of indicators on health impact, building deterioration, vegetation damage, etc., should be adequately documented and linked to public awareness. Selected indicators should respond to mitigation actions to prevent manmade negative impacts on the environment.

3.1 The Conceptual Framework

In general terms, an indicator can be defined as a parameter, or a value derived from parameters, which provides information about a phenomenon. The indicator has significance that extends beyond the properties directly associated with the parameter value. Indicators possess a synthetic meaning and are developed for a specific purpose. This points to two major functions of indicators:

1. They reduce the number of measurements and parameters which normally would be required to give an "exact" presentation of a situation;
2. They simplify the communication process by which the results of measurement are provided to the user.

3.1.1 Definition of Terms

INDICATOR

A parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value.

INDEX

A set of aggregated or weighted parameters or indicators.

PARAMETER

A property that is measured or observed.

INDICATORS OF ENVIRONMENTAL PRESSURES

Correspond to "pressure" box of PSR framework. They describe pressures on the environment caused by human activities.

INDICATORS OF ENVIRONMENTAL CONDITIONS

Correspond to "state" box of the Pressure State Response framework. They comprise environmental quality and aspects of quantity and quality of natural resources.

RESPONSE INDICATORS

Correspond to "response" box in PSR framework. In the present context, the word "response" is used only for societal (not ecosystem) response.

INDICATORS FOR USE IN PERFORMANCE EVALUATION

Selected and/or aggregated indicators of environmental conditions, indicators of environmental pressures and indicators of societal responses for the purpose of environmental performance evaluation.

ENVIRONMENTAL INDICATORS

All indicators in the Pressure State Response framework, i.e. indicators of environmental pressures, conditions and responses.

As indicators are used for varying purposes it is necessary to define general criteria for the selection of indicators. Three basic criteria have been used in OECD work: policy relevance, analytical soundness and measurability (OECD, 1994).

In large parts of its work, the Group on the State of the Environment uses the Pressure State Response (PSR) framework. The PSR framework (Figure 7) is based on a concept of causality:

- Human activities exert <u>pressures</u> on the environment and change its <u>state ;</u> i.e. quality and the quantity of natural resources.
- Society <u>response</u> to these changes through environmental, general economic and sectoral policies.

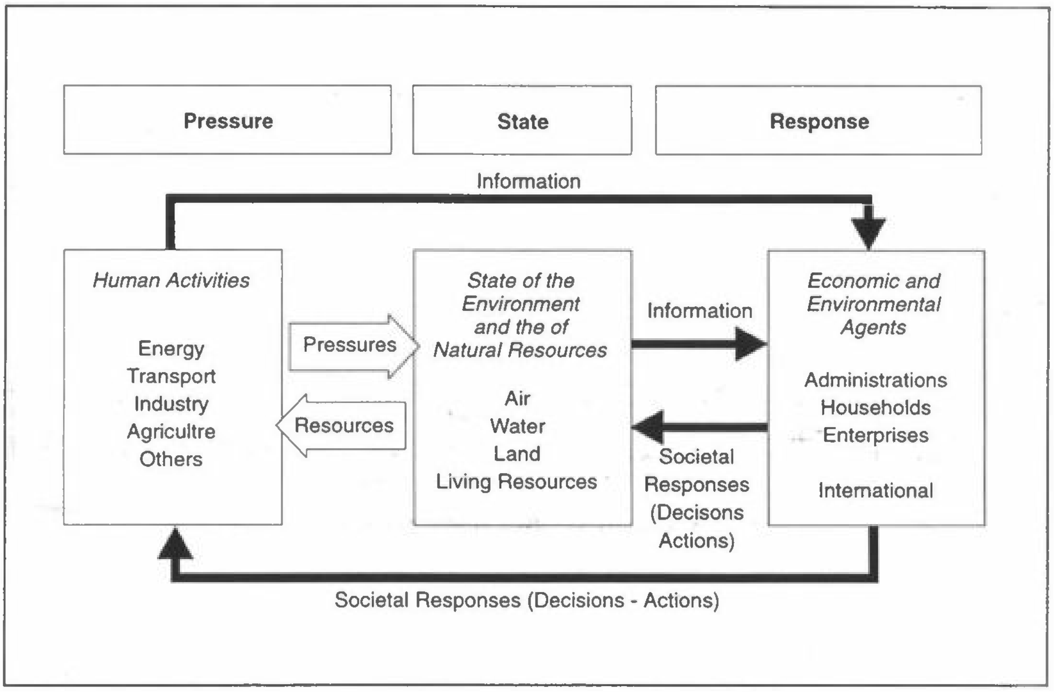


Figure 7: Pressure State Response Framework.

3.2 Selected Air Quality Indicators (AQI)

Air quality indicators have been selected for different environmental issues and challenges. Not all indicators are specific enough to address only one issue. The nature of air pollution involve that some indicators address several issues. Some of the issues that have to be addressed are

- climate change,
- ozone layer depletion,
- acidification,
- toxic contamination,
- urban air quality,
- traffic air pollution.

As can be seen from the list the indicators have to cover all scales of the air pollution problems (in space and time) to address different type of impacts and effects.

In Europe different indicators have been established for characterizing different air pollution types, as examplified in Table 1. (Sluyter, 1995)

Table 1: Indicators selected for different types of air pollution in Europe. The number of cities in Europe where given Air Quality Guideline (AQG) values are exceeded are given. (Sluyter, 1995)

Pollution type	Indicator	AQG (μg/m^3)	Cities with observed exceedances (%)	Effects
Short term effects				
Summer smog	O_3	150-200 (hour)	84	Lung function decrements, respiratory symptoms
Winter smog	SO_2+PM	125+125 (day)	74	Decreased lung function; increased medicine use for susceptible children
Urban traffic	NO_2	150 (day)	26	
Long term effects				
Traffic/industry	Lead	0.5-1.0 (year)	33	Effects on blood formation, kidney damage; neurologic cognitive effects
Combustion	SO_2	50 (year)	13	Respiratory symptoms, chronic respiratory illness
	PM	50 (year)	0	

The most commonly selected air quality indicators for urban air pollution are carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particles with aerodynamic diameter less than 10 μm (or 2,5 μm), PM_{10} ($PM_{2,5}$) and ozone.

Some selected air quality guideline (AQG) values for these indicators are presented in Table 2:

Table 2: Typical air quality guideline (AQG) values for some selected indicators based on impact on public health (WHO, 1987 and 1995)

Indicator	AQG (μg/m^3) averaging time		
	1 h	24 h	Year
CO (mg/m^3)	100	10 (8 h)	-
NO_2 (μg/m^3)	200		40-50
SO_2 (μg/m^3)	500	125	50
PM_{10} (μg/m^3)	-	70**	-
Black Smoke*	125	50	-
Ozone (μg/m^3)	150-200	120***	-

* Together with SO_2

** Norway (SFT)

*** 8 h average (1995 recommend.)

The most important indicators when discussing health impacts especially linked to respiratory hypersensitivity are considered to be oxidized pollutants such as NO_2 and ozone. SO_2 combined with acid aerosols are also associated with respiratory problems. For particulate matter the particle size plays an important role. Primarily the fine fraction (<2,5 µm) of particles, often associated with strong aerosol acidity or sulphates or correlated with gaseous components, is assumed to impact the respiratory system.

It should also be noted that a common feature of exposure to the primary compounds NO_2, SO_2, ozone and PM (particulate matter) id that the resulting health effects may be altered in the presence of other compounds and/or aeroallergens. The interaction of the compounds can be synergistic. These considerations are generally not taken into account when AQG values are established.

Although the AQG take into account the most sensitive populations, known or supposed interactions with climatic factors are not accounted for. The existence of a threshold value has not necessarily been documented for all compounds. For compound where this is the case there is normally a safety margin between the lowest known effect and the AQG value.

Peak statistic bar charts have been produced for acute health effect indicators for each criteria pollutant and the annual mean lead concentration. An example of this is presented in chapter 7. The indicators for which bar charts have been elaborated are shown in Table 3.

Table 3: Indicators for elaboration of air quality status in OECD cities

Pollutant	Unit	Indicator
Carbon monoxide	mg/m^3	Annual max. 8-hour running average
Nitrogen dioxide	$\mu g/m^3$	Annual average
Ozone	$\mu g/m^3$	Annual max. 1-hour average Annual max. 8-hour running average
Particulate matter	$\mu g/m^3$	Annual max. 24-hour average
Sulphur dioxide	$\mu g/m^3$	Annual max. 1-hour average Annual max. 24-hour average

Air pollution concentrations in OECD cities have been compared to WHO Guideline criteria which enables assessment of the likely impact of the air quality upon health. Some of the indicators adopted by the OECD have been discontinued in the revised WHO Guidelines.

Recently WHO has presented new proposed air quality guidelines for protection of terrestrial vegetation. These proposals are presented in Table 4.

Table 4: New proposed Air Quality Guideline values presented to protect terrestrial vegetation (WHO, 1995)

Substance	Guideline value µg/m^3	Averaging time	Remarks
Nitrogen dioxide	95	4 hours	In the presence of SO_2 and O_3 levels which are not higher than 30 µg/m^3 (arithmetic annual average) and 60 µg/m^3 (average during growing season
	30	1 year	
Total nitrogen deposition	3 g N/m^2	1 year	Sensitive ecosystems are endangered above this level
Sulphur dioxide	30	1 year	Insufficient protection in the case of extreme climatic and topographic conditions.
	100	24 hours	
Ozone	65	24 hours	Vegetation
	60	100 days	Growing season
Peroxyacetylnitrate	300	1 hour	Vegetation
	80	8 hours	Vegetation

4. Monitoring Programme

4.1 Programme design

As part of the establishment of an air quality monitoring and surveillance system, a programme has to be established to design and plan the details and content of such a system. This programme should be undertaken including the following topics:

1. Define the objectives and strategies for the measurement programme,
2. define the contents,
3. perform a screening,
    - problems and relevant air pollution sources,
    - collect available data (meteorology and air quality),
4. evaluate existing data,
    - representativeness equipment,
    - QA procedures,
5. plan the programme in detail,
    - siting studies,
    - consider field investigations,
    - emission inventorying, simple modelling,
    - select relevant sites,
6. optimize measurements, (cost/effective design),
7. procure instruments,
    - specify technical requirements,
8. establish and initiate operation,
    - laboratory control systems,
    - develop standard operational procedures (SOP),
    - define and describe QA/QC procedures,
9. training.

A general objective for the air quality measurement programme (monitoring, sampling and analysis) is often to adequately characterize air pollution for the area of interest, with a minimum expenditure of time and money. The measurement and sampling techniques to be used in each case will be dependent upon a complete analysis of the problem. The main objectives stated for the development of an air quality measurement and surveillance programme might be:

1. Background concentrations measurements,
2. air quality determination to check ,
    - air quality standards to monitor current levels,
    - to detect individual sources,
    - to collect data for land use planning purposes,
3. observe trends (related to emissions),
4. develop abatement strategies,
5. assess effects of air pollution on health, vegetation or building materials,
6. develop warning systems for prevention of undesired air pollution episodes,
7. research investigations,
8. develop and test diffusion models,
9. develop and test analytical instruments.

Once the objective of air sampling is well defined, a certain operational sequence has to be followed. A best possible definition of the air pollution problem together with and analysis of available personnel, budget and equipment represent the basis for decision on the following questions:

1. What spatial density of sampling stations is required?
2. How many sampling stations are needed?
3. Where should the stations be located?
4. What kind of equipment should be used?
5. How many samples are needed, during what period?
6. What should be the sampling (averaging) time and frequency?
7. What other than air pollution data are needed:
    - meteorology,
    - topography,
    - population density,
    - emissions,
    - effects, etc.?
8. What is the best way to obtain the data (configuration of sensors and stations)?
9. How shall the data be communicated, processed and used?

The answers to these questions will vary according to the particular need in each case. Most of the questions will have to be addressed in the siting studies discussed in the next chapter.

4.2 Siting

4.2.1 Representativity

It is important to bear in mind, when measuring air quality or analyzing results from measurements, that the data you are looking at is a sum of impacts or contributions originating from different sources on different scales.
The total concentration is a sum of

- a natural background concentration,
- a regional background,
- a city average background concentration (kilometre scale impact),
- local impact from traffic along streets and roads,
- impact from large point sources; industrial emissions and power plants.

To obtain information about the importance of these different contributions it is therefor necessary to locate monitoring stations so that they are representative for the different impacts. This normally means that more than one monitoring site is needed for characterizing the air quality in the urban area. It is also important to carefully characterize the monitoring representativeness, and to specify what kind of stations we are reporting data from. An often used terminology is

- urban traffic,
- urban commercial,
- urban residential and
- rural sites.

When considering the location of individual samplers, it is essential that the data collected are representative for the location and type of area without undue influence from the immediate surroundings.

In the design of an urban air quality monitoring programme the following general guidelines should be considered:

- All stations (air intake) should be located at the same height above the surface, a typical elevation in residential areas is 2 to 6 m above ground level.
- Constraints to the ambient airflow should be avoided by placing the air intake at least 1,5 meters from buildings or other obstructions.
- The intake should be placed away from microscale or local time varying sources.

4.2.2 Sampling Station Density

The number of stations needed to answer the objectives of the air pollution sampling, depends on many factors such as

- types of data needed,
- mean values and averaging times,
- frequency distributions,
- geographical distributions,
- population density and distribution,
- meteorology and climatology of the area,
- topography and size of area,
- location and distribution of industrial areas.

A rough indication of the minimum number of sampling stations needed as a function of population density is given in Figure 8. for a typical community air quality network. Automatic continuous sampling equipment in general involve fewer stations than an integrating sampling device (24 hr average or more).

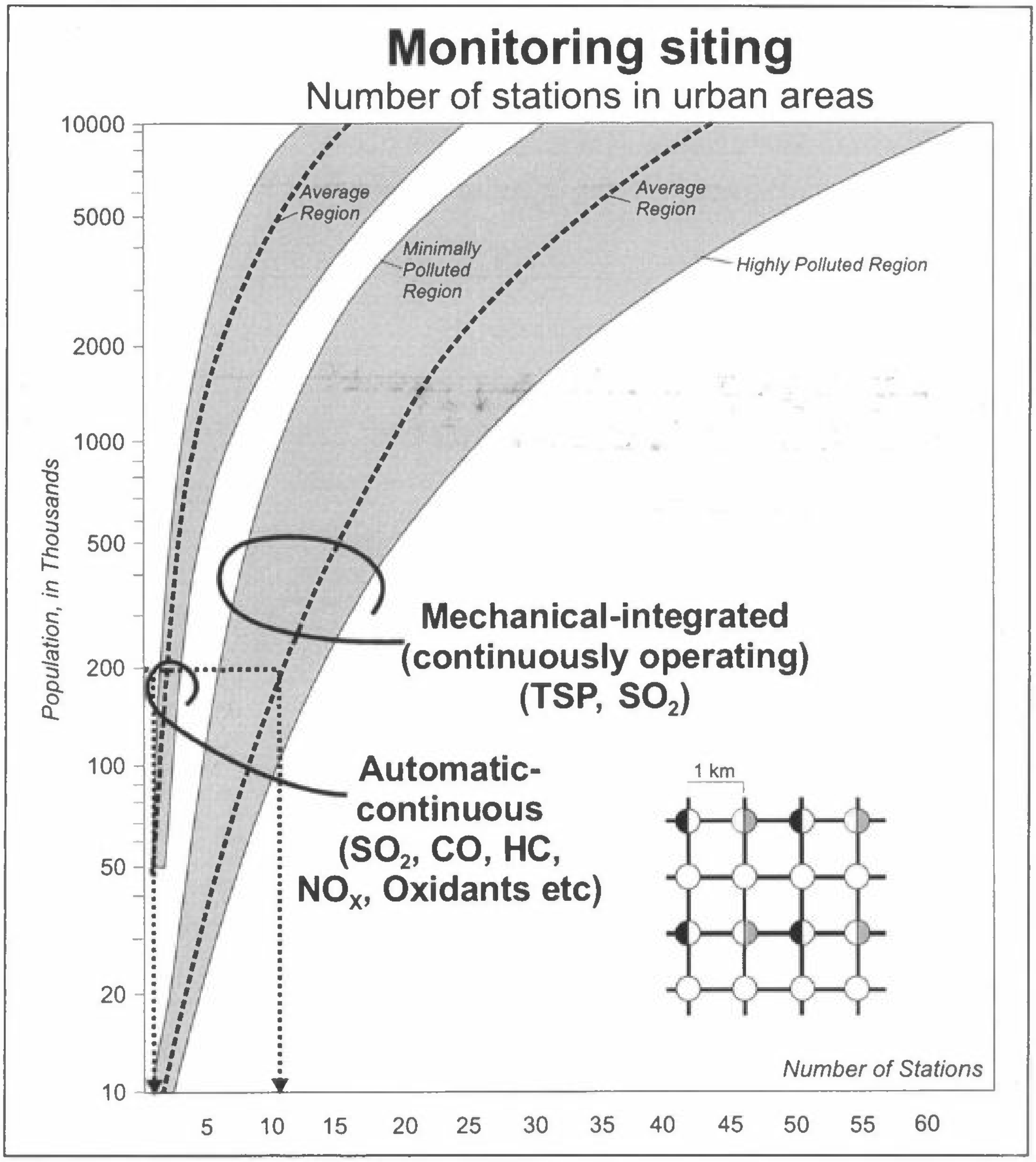


Figure 8: Minimum number of measurement stations needed for a typical community air quality measurement network.

The selection of sampling time is a function of the air pollutant characteristics (emission rate, life time) and time specifications of the air quality criteria.

The ability of combining the air quality data with meteorological data through dispersion modelling, also is a very important tool in the design of sampling networks.

If the location of the maximum air pollution area is known from a limited information about the region's meteorology, and the only objective is to check that air quality standards are met, in some cases even one sampling station may be sufficient.

In a topographical complex area with hills, valleys, lakes, mountains etc., there are considerable local spatial and temporal variations of the meteorological parameters, and thus the dispersion conditions. To answer the same questions, more sampling stations are needed in such areas than in flat homogeneous terrain.

Typical for a flat area is also that spaced stations (as proposed by the German Federal regulations or as is the New York City's aerometric network) average out spatial variations and thus can give net results representative for the area as a whole.

4.3 Air quality measurement instrumentation

Instruments for measurements of air pollutants may vary strongly in complexity and price from the simplest passive sampler to the most advanced and most often expensive automatic remote sampling system based upon light absorption spectroscopy of various kind. The following Table indicate four typical types of instruments, their abilities and prices.

Table 5: Different types of instruments, their abilities and price.

Instrument type	Type of data collected	Data availability	Typical averaging time	Typical price (US $)
Passive sampler	Manual, in situ	After lab analyses	1-30 days	10
Sequential sampler	Manual /semi-automatic , in situ	After lab analyses	24 h	1 000
Monitors	Automatic Continuous, in situ	Directly, on-line	1h	>10 000
Remote monitoring	Automatic/Continuous, path integrated (space)	Directly, on-line	<1 min	>100 000

Relatively simple equipment is usually adequate to determine background levels (for some indicators), to check Air Quality Guideline values or to observe trends. Also for undertaking simple screening studies, passive samplers may be adequate. However, for complete determination of regional air pollution distributions, relative source impacts, hot spot identification and operation of warning systems more complex and advanced monitoring systems are needed. Also when data are needed for model verification and performance expensive monitoring systems are usually needed.

4.3.1 Passive samplers

Simple passive samplers have been developed for surveillance of time integrated gas concentrations. These type of samplers are usually inexpensive in use, simple to handle and have an adequate overall precision and accuracy dependent upon the air pollution concentration level in question. This method has been used in industrial areas, in urban areas and for studies of indoor/outdoor exposures.

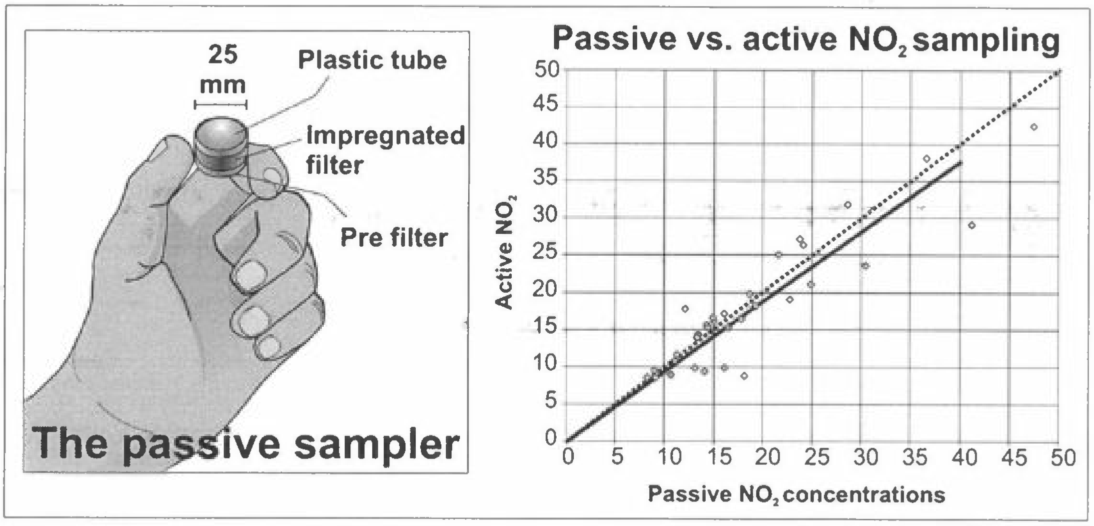


Figure 9: a) A passive impregnated filter sampler based on molecular diffusion.
b) The integrated passive sampling of SO_2 and NO_2 is well correlated with available active sampling methods

A sensitive diffusion sampler for sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) developed by the Swedish Environmental Research Institute (IVL) and has been used in several investigations by NILU to undertake a screening of the spatial concentration distribution in ambient air.

The sampler includes an impregnated filter inside a small plastic tube. To avoid turbulent diffusion inside the sampler, the inlet is covered by a thin porous membrane filter. Gases are transported and collected by molecular diffusion. The uptake rate is only dependent upon the diffusion rate of the gas. The collection rate is 31 l/24h for SO_2 and 36 l/24h for NO_2. Also NH_3 can be collected at a rate of 59 l/24h.

For SO_2 the measuring ranges are approximately 0,1-80 ppb for a sampling period of one month. The corresponding range for NO_2 is 0,02-40 ppb. The passive samplers are assembled and made ready for use at NILU .After exposure the samplers are usually returned to NILU where concentrations of SO_2 are determined as sulphate by ion chromatography. NO_2 and NH_3 is determined by spectrophotometry.

The passive samplers have been used in several field studies to map concentration distributions, both as part of a screening to identify the magnitude of the problem and for modelling purpose to estimate total emission rates and possible impacts. The NO_2 concentration distribution in Oslo on a winter day is only one example shown in Figure 10.

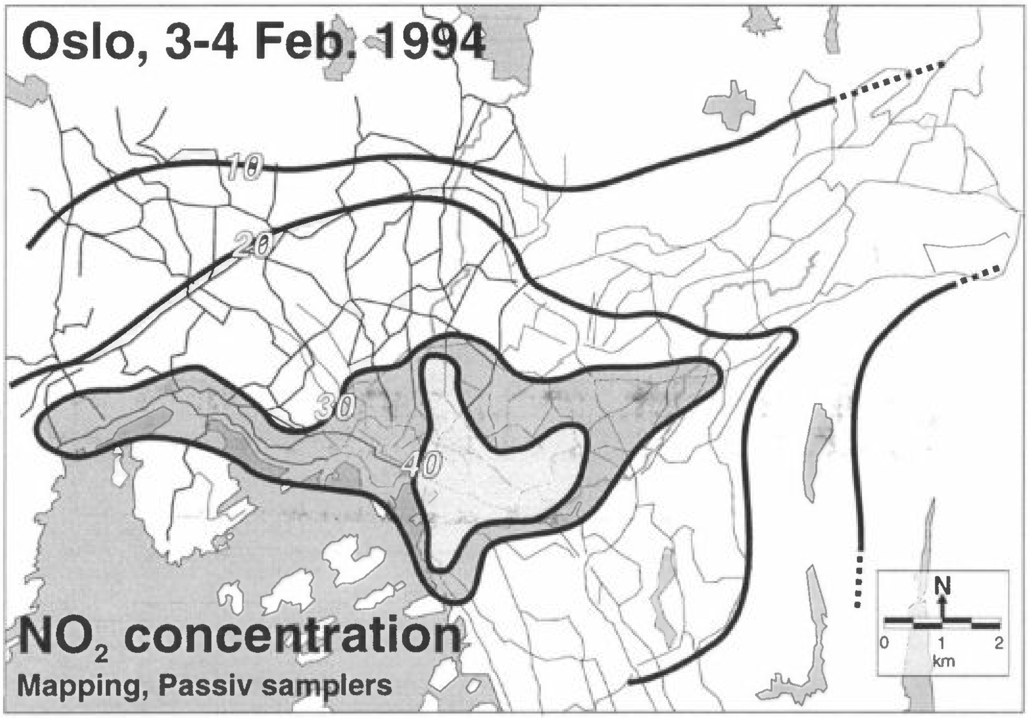


Figure 10: The 24 h average NO$_2$ concentration distribution for Oslo measured on 3 -4 February 1994 with 20 passive samplers show that the highest concentrations occurred along the main road systems and in central parts of down-town Oslo. This 24 h average distribution may change considerably from one day to the next depending on meteorological conditions in the Oslo airshed.

4.3.2 *Filter pack sampling*

The filter pack for air sampling consists of a filter holder with a teflon pre-filter for particles and two impregnated paper filters for gases. The filter holder is connected to a pump with flow controller which pull a steady airflow through the filters. The detection limit is better than for the other methods but the method is more labour intensive and is dependent of extra sampling equipment such as a high precision electric pump.

4.3.3 *Glass filter sampling*

The Glass filter sampler consists of a glass bulb with a impregnated glass filter inside. The glass bulb is connected to a calibrated pump that draws a steady airflow through the filters. After exposure the glassbulb is sent to the laboratory for analysis, then the filter is washed and used again. The detection limit is better than for the other methods but the method is more labour intensive and depends of extra sampling equipment such as a high precision electric pump.

4.3.4 Canister sampling

Canister sampling can be used for volatile hydrocarbons up to C9. Air samples are collected in stainless steel canisters by the aid of a pump or just by opening the valve of an evacuated canister. The canisters are sent to the laboratory for analysis and then cleaned by evacuating it (vacuum).

4.3.5 Adsorbent tubes

Adsorbent tubes can be used for sampling of a wide number of volatile organic compounds. The tubes can be filled with different kinds of adsorbents, depending of which components of interest. When used as a passive sampler, there is no need for any extra equipment. To decrease the minimum sampling period or to improve the detection limit, the tube can be connected to a pump.

Adsorbent tubes are not suitable for some of the most volatile hydrocarbons.

4.3.6 High volume PUF-sampler

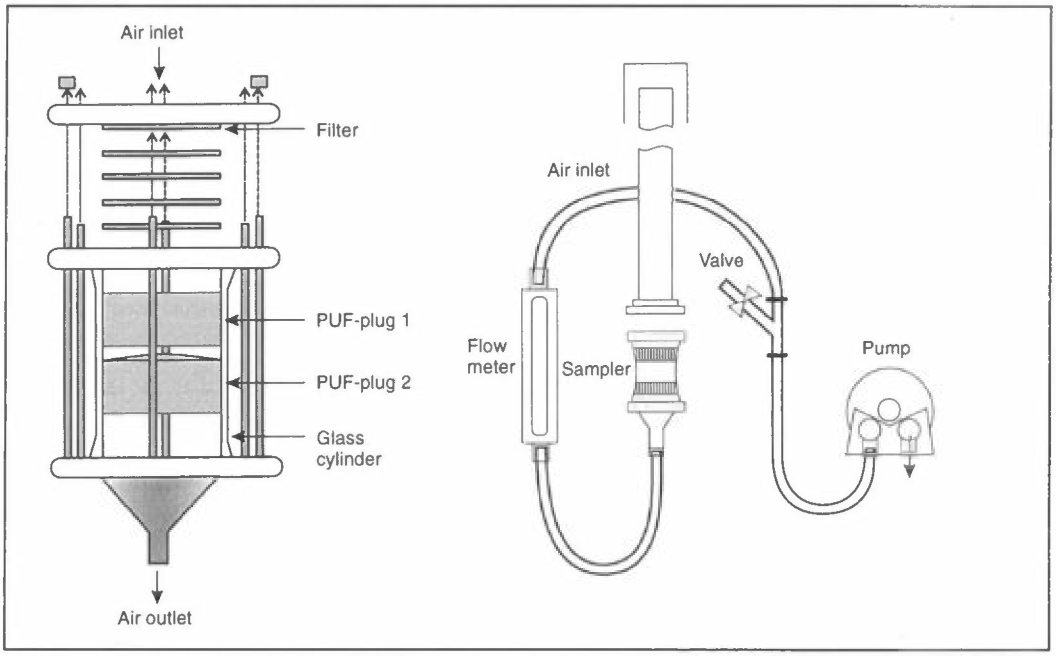


Figure 11: The NILU high volume PUF (polyurethane foam) sampler.

The high volume PUF-sampler can be used for sampling of a wide spectre of organic pollutants like polyaromatic hydrocarbons (PAH), dioxins, pesticides (like DDT) etc.

The sampler consists of a glass cylinder and a filter holder. The glass cylinder holds two polyurethane foam (PUF) plugs for trapping the gas phase of the pollutants. The filter holder in front holds a glass fibre filter to collect pollutants condensed on particles.

The air is drawn through the sampler by a pump. 500 m^3 of air would be a typical sample volume for a 24 hour sample.

4.3.7 Precipitation dust fall collection

Precipitation samples are collected in plastic cans. To avoid evaporation during the hot season, the liquid is normally collected through a narrow inlet into a jar. Dust fall is collected in open buckets (see Figure 12). The collection periods vary from 1 day/week (for precipitation) to 30 days for dust fall.

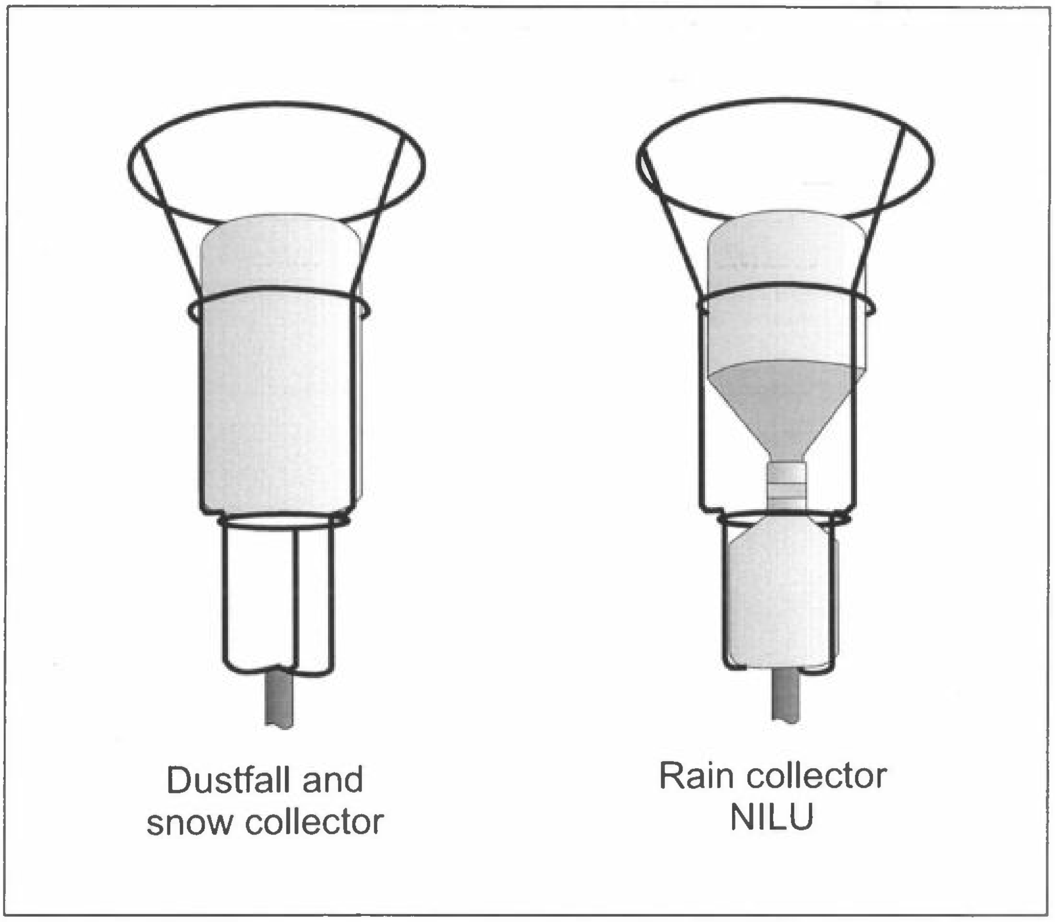


Figure 12: The NILU dust fall and precipitation collector.

When analysing heavy metals, the cans are sent to the laboratory where the samples are analysed and the cans are cleaned with acid. If no heavy metals are analysed, only a portion of the samples are taken out of the can and sent to the laboratory. The can is then flushed with cleaned water and used again. All precipitation samples are stored in a cool place.

4.3.8 Semi-automatic sequential samplers

The determination of pollutant concentrations undertaken by samplers requires that a sample is brought to the chemical laboratory for analysis.

Traditionally, sampling and analysis have been described as separate events. This is due to the fact that until the early seventies, ambient air quality was conducted by sampling systems that were for the most part intermittent, and which provided average rather than real-time measurements. Intermittent sampling systems collect gases in a solution or particles on a filter, typically over a period of 24 hours. For most programmes of this type such a sample is collected only once every 6 day.

A few semi-automatic sequential samplers have been developed and are still available on the marked. These have been widely used, especially in Europe, for daily average SO_2, NO_2, and PM/Black Smoke (BS) sampling.

After collection, the sample is removed from the collection device and transported to the laboratory where it is analyzed manually by chemical or physical methods.

The air quality sampler involves four steps as shown in Figure 13; an inlet system to bring air to a collection device where the pollution is measured or prepared for analysis, an air flow meter where the volume of air is measured and controlled at a constant rate and an air mover which draws air through the system.

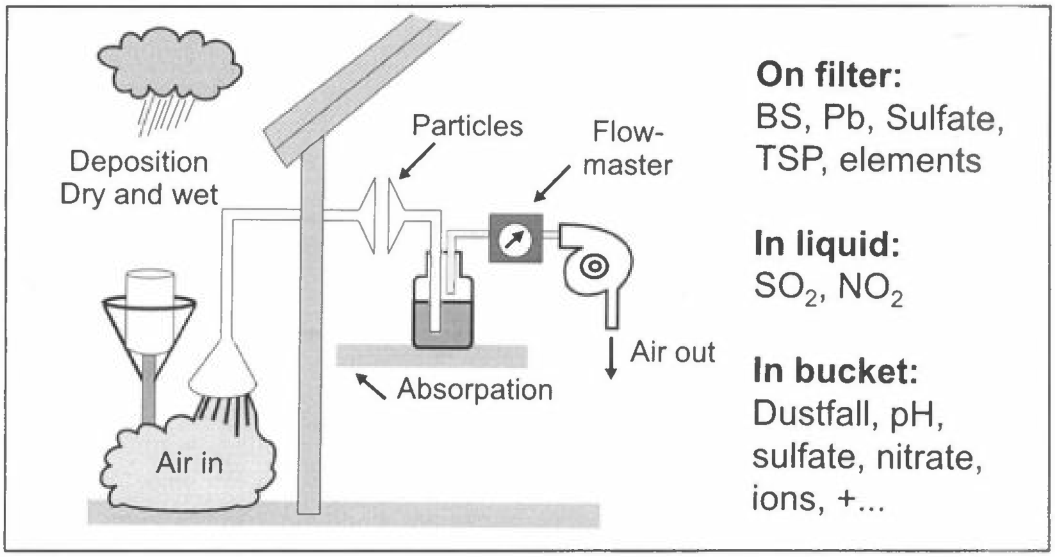


Figure 13: A typical inlet system for the ambient air pollution sampler.

The inlet system must be clean and made of a material that does not react with the air pollutants. Glass is often preferred. With long inlet systems the time required for a volume of air to reach the collection device must be considered. In addition to time lag, the problem of reaction between the various pollutants with each other during the transfer may arise, due to for instance a higher temperature inside the sampling tube than ambient air. This is particularly so when sampling nitrogen oxides and ozone. In such cases a system with high flow rates should be considered to reduce or minimize the time lag.

The methods of collecting gases and particulate matter include:

- adsorption
- absorption
- freeze-out
- impingement
- thermal and electrostatic precipitation
- direct measurement
- mechanical filtration.

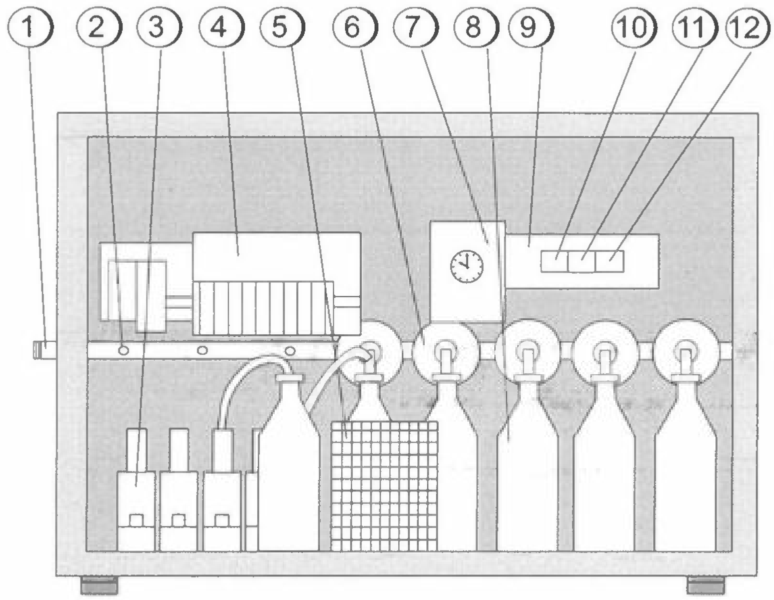
The collection device is based on discrete sampling periods, semicontinuous or continuous sampling coupled to a recorder or a computer network.

Automatic sequential samplers have been developed and used for collection of time integrated samples with averaging times from a few hours and usually up to 24 hours.

The most commonly used device has been the bubbler, often together with a filtration system. A chemical solution is used to stabilize the pollutant for subsequent analysis with minimum interference by other pollutants.

To determine the pollutant concentration, it is necessary to measure the air volume sampled. The gas flow rate or the total gas volume sampled. The gas flow rate or the total gas volume integrated over the sampling period may be determined using gas flow meters, rotameters, anemometers or liquid burettes. Temperature and pressure corrections are taken to convert the air volume to standard conditions.

The air mover may be an electrical or battery-powered pump, a squeeze bulb or a vacuum system.



1. Intake to manifold
2. Manifold
3. Solenoid valve
4. Programmable sample exchange unit
5. Pump exchange
6. Filter holder
7. Timer
8. Absorption bottle
9. Panel
10. Power switch (on/off)
11. SHIFT, button for manual sample
12. STOP, button for automatic stop

Figure 14: 24-hours NILU sequential air sampler (FK).

4.3.9 Particulate matter sampling

Particles may be collected by a variety of techniques including

- gravitational settling,
- filtration,
- electrostatic and thermostatic precipitation and
- impaction.

Gravitational settling, filtration and impaction have been the most widely used methods for ambient particulate sampling.

The simplest particulate sampling method employs the principle of gravitational settling of large falling particles. These are collected in a open top bucket placed in the atmosphere for a typical period of 30 days (see Figure 12). This static or passive sampling method require no air-moving equipment.

Hi-vol sampling

The high volume sampler has been most common in air quality monitoring programmes world wide. The principle is shown in Figure 15.

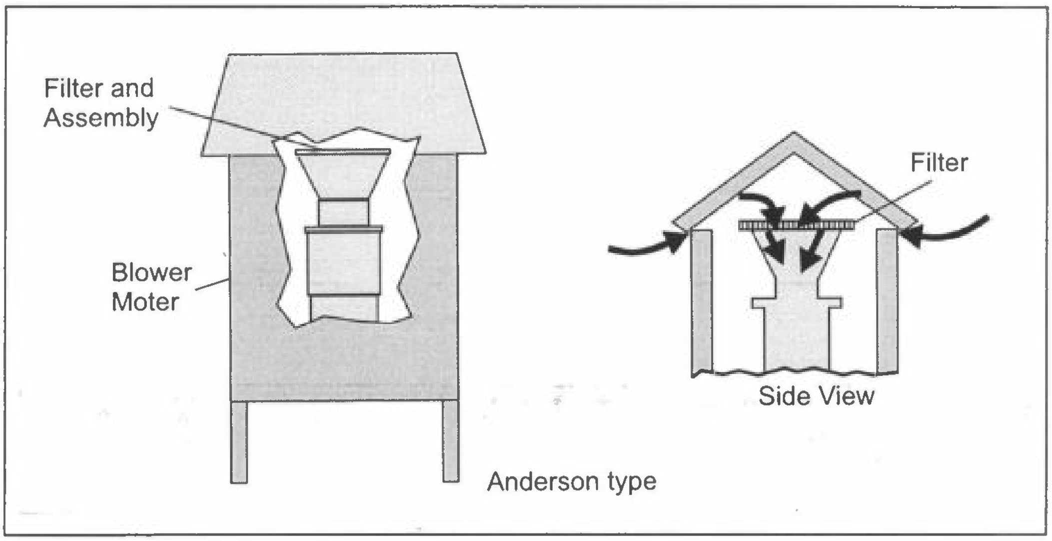


Figure 15: The hi-vol samplers principle.

A collecting glass fibre filter is located upstream of a heavy-duty vacuum pump which operates on a high flow rate of 1 to 2 m^3 /min. The sampler is mounted in a shelter with the filter parallel to the ground. The covered housing protects the glass fibre filter from wind and debris, and from the direct impact of precipitation. The hi-vol collects particles efficiently in the size range of 0.3-100 micrometers. The mass concentration of total suspended particles (TSP) is expressed as $\mu g/m^3$ for sampling times of usually 24 hours.

Paper tape samplers

In contrast to the hi-vol sampler, paper tape samplers are semi continuous with averaging times of about one to two hours as normal.

Paper tape samplers draw ambient air through a cellulose tape filter. After a two hour sampling period, the instrument automatically advances to a clean piece of tape and begins a new sampling cycle.

Advanced paper tape samplers are equipped with densitometers for optical density measurements during the sampling period. These instruments record changes in light transmission which can be converted into COH (Coefficient of Haze) units. Simpler instruments without built in densitometers necessitate manual determination of optical density in the laboratory.

COH units are based on light transmission through the soiled filter area. The higher the ambient particle loading, the more soiled the filter. The subsequent increase in optical density can in most instances be directly related to mass concentration.

In the early 70s, paper tape samplers were widely used for continuous monitoring of particulate matter concentrations. Because of difficulties in relating data acquired by this optical method to the gravimetric data of the hivol reference method, most paper tape sampling has been discontinued. Paper tape samplers are still used on a standby basis in metropolitan areas where rapid data acquisition is essential to implement episode control plans during stagnating anticyclones.

Size Selective Samplers.

A variety of sampling devices are available that segregate collected suspended particulate matter into discrete size ranges based on their aerodynamic diameters. These particle samplers may employ one or more fractionating stages. The physical principle by which particle segregation or fractionation takes place is inertial impaction. Therefore, most such devices are called impactors.

In impactors, air is drawn through the unit and deflected from its original path of flow. The inertia of suspended particles causes them to strike or impact a deflecting surface, where they are collected. The size range of particles collected on the impaction surface depends on

(1) gas velocity,
(2) particle density and shape,
(3) air flow geometry,
(4) gas viscosity, and
(5) the main free path of the gas.

Multi stage or cascade impactors can fractionate suspended particles into six or more size fractions. In theory each stage collects particles above a certain "cut-off" diameter which is smaller than the previous stage.

Other impactors have been developed to fractionate suspended particles into two size fractions, i.e., coarse (from 2.5-10 µm) and fine (less than 2.5 µm). Although these virtual or dichotomous impactors operate like a typical inertial unit, large particles are impacted into a void rather than an impervious surface. Both size fractions are then collected on individual membrane filter paper. A dichotomous impactor is illustrated in Figure 16.

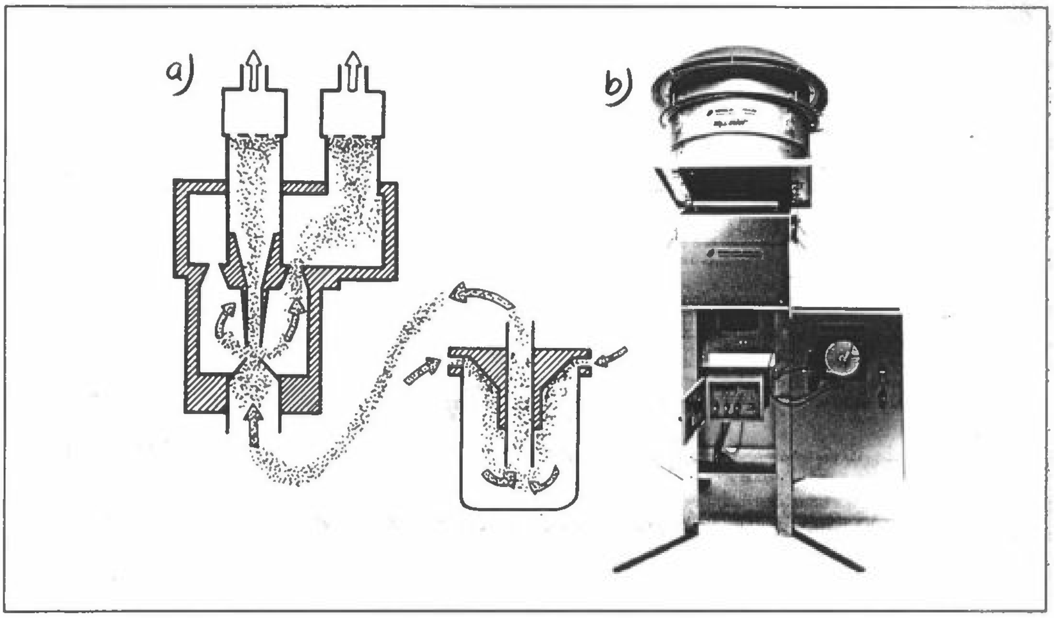


Figure 16: Size selective samplers.
a) The dichotomous impactor as used by Andersen samplers,
b) The hi-vol sampler with size selective inlet (General Metal works)

In 1987, the primary air quality standard for particulate matter was changed from measurements of mass particulate matter concentrations that ranged upward of 100 µm in diameter to a so-called PM_{10} standard, which included only those suspended particles of less than 10 µm aerodynamic diameter.

The approved monitoring method to establish compliance with the new PM_{10} standard requires the use of devices that inertially separate suspended particulate matter into one or more size fractions within the PM_{10} size range. A variety of devices are likely to meet the performance specifications for the EPA reference method for PM_{10}, including both cascade and dichotomous impactors. Another device, a modification of the hi-volume sampler, is also likely to be used. A modified hi-volume sampler with a size selective inlet is shown in Figure 16b. Collection of particles in this device is based on inertial separation of PM_{10} particles followed by filtration.

4.3.10 Continuous automatic monitors

Methods and instruments for measuring continuous air pollutants must be carefully selected, evaluated and standardized. Several factors must be considered:

- *Specific*, i.e. respond to the pollutant of interest in the presence of other substances,
- *sensitive* and range from the lowest to the highest concentration expected,
- *stable*, i.e. remain unaltered during the sampling interval between sampling and analysis,
- *precise, accurate* and representative for the true pollutant concentration in the atmosphere where the sample is obtained,

- adequate for the *sampling time* required,
- *reliable and feasible* relative to man power resources, maintenance cost and needs,
- zero drift and calibration (at least for a few days to ensure reliable data),
- response time short enough to record accurately rapid changes in pollution concentration,
- ambient temperature and humidity shall not influence the concentration measurements,
- maintenance time and cost should allow instruments to operate continuously over long periods with minimum downtime,
- data output should be considered in relation to computer capacity or reading and processing.

If one consider the typical air concentrations of some pollutants of interest in air pollution studies, it is seen from Table 6 that as we go from background to urban atmosphere, the concentration for the most common pollutants increase roughly by a factor 1000, in the next step from urban to emission we see another factor of about 1000.

Table 6: Typical concentrations of pollutants in samples of interest in air pollution.

Pollutant	Background	Urban ambient	Stack effluents
CO	0.1 ppm	5-10 ppm	2,000-10,000 ppm
SO_2	0.2 ppb	0.02-2 ppm	500- 3,500 ppm
NO_x	0.2-5 ppb	0.2-1.0 ppm	1,500- 2,500 ppm
O_3	10 ppb	0.1-0.5 ppm	-
Suspended particulates	10 µg/m^3	60 µg/m^3	35x10^6 µg/m^3
Methane	1.5 ppm	1-10 ppm	
Other hydrocarbons	<ppm	1-100 ppb	

Few techniques or instruments are capable of measuring the total range of 10^6 ppm. Also the ambient conditions (temperature, humidity, interfering substances etc.) may differ greatly from ambient to emission measurements. The selection of sampling system is thus influenced by the expected concentration level and the surrounding conditions. We usually find that instruments, techniques and analytical approaches are designed for application of specific concentration ranges as represented by background levels, ambient urban air concentration levels and typical stack emission concentrations.

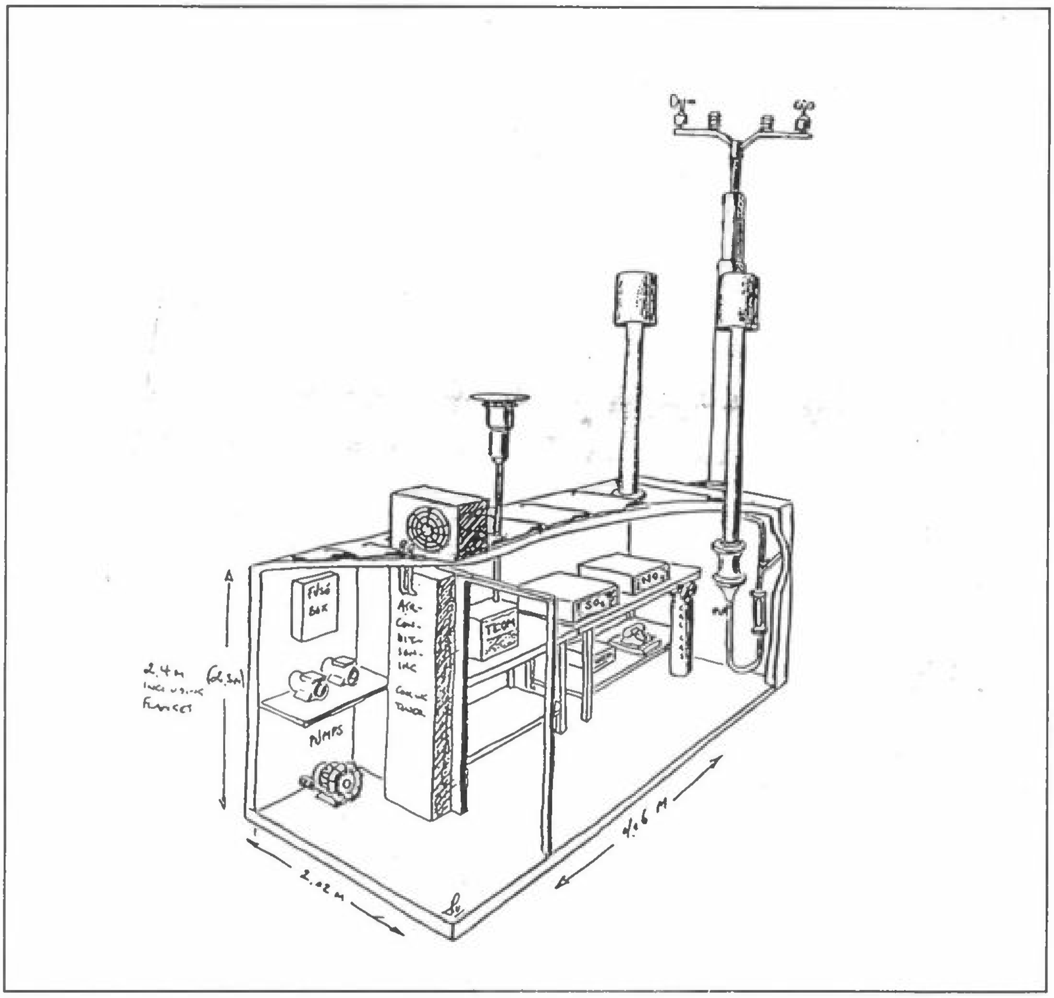


Figure 17: A typical monitoring station including gases, particles and meteorology.

The most commonly used methods for monitoring some of the major air quality indicators are discussed in the following:

Sulphur dioxide (SO_2)

SO_2 should be measured from the fluorescent signal generated by exciting SO_2 with UV light. The internal zero span selfcheck option includes a temperature controlled permeation tube, TFE zero span valves and a zero air scrubber. The zero check and calibration can be performed remotely from contact through a RS232 command. Daily controls can thus be performed from the central laboratory PC-system. The computer operating system continuously monitors all critical operating points of the instrument to confirm proper operations.

Nitrogen oxides (NO and NO_2)

The principle of chemilumiscent reactions between NO and O_3 will be used for measuring NO_x. NO and total NO_x is being measured. NO_2 is estimated after reduction of NO_2 by catalytic converter. NO_2 measurements can be made even in areas with rapidly changing NO concentrations. A multi-tasking computer operating system continuously monitors all critical operating points in the instrument to confirm proper operations. A built-in data display presents trends, averages, status, and historical information in digital or graph format.

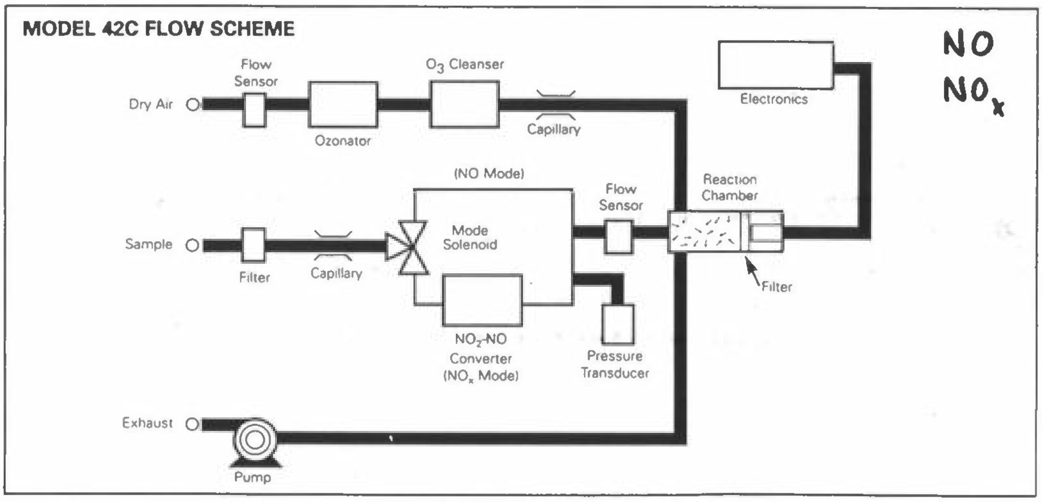


Figure 18: A typical flow scheme for a NO-NO_x-monitor.

Ozone (O_3)

An ultraviolet absorption analyzer will be used for measuring the ambient concentrations of ozone. The concentration of ozone is determined by the attenuation of 254 nm UV light along a single fixed path cell. The ozone molecule is a strong absorber of the 254 nm energy and thus the energy lost over the fixed path is proportional to the ozone concentration in the atmosphere.

The remote control/ remote programming capability permits long distance operations through a modem communication to the analyzer via a RS232 port. Calibrations and controls can thus be performed from a central laboratory computer.

Suspended particles ; TSP, PM_{10} and $PM_{2.5}$

Gravimetric methods including a true micro weighing technology will be used to measure ambient concentrations of suspended particulate matter. We will suggest an instrument named "Tapered Element Oscillating Microbalance (TEOM)". Using a choice of sampling inlets, the hardware can be configured to measure TSP, PM_{10} or $PM_{2,5}$. International standards and requirements recommend that at least PM_{10} should be measured.

The microprocessor based unit easily accommodates all siting requirements and provides internal data storage and advanced analogue and serial data input/output capabilities. The technique allows for near continuous measurements and data transfer via modem and telecommunication to a central laboratory .

Carbon monoxide (CO)

The CO analyzer proposed for this project is a non-dispersive infrared photometer that uses gas filter correlation technology to measure low concentrations of CO accurately and reliable by use of state-of-the-art optical and electronic technology. When environmental conditions change, the instrument automatically zeros itself by drawing in air, which passed through a catalyst to remove CO, and stores the information in the memory of a micro processor. All readings are corrected before output.
The display, graphics, printouts and RS232 outputs are autoranging. All data can be retrieved through a modem and telephone line to a central laboratory .

Hydrocarbons and VOC

Hydrocarbons (NMHC, Methane and THC) should be measured using a flame ionization detector (FID).

4.3.11 Open path measurements based on optical absorption

A new generation of instruments have been developed that is based upon the principle of differential optical absorption spectroscopy (DOAS).These are automated methods (analyzers) that can measure pollutant concentrations in the ambient air over a long, open path up to one kilometre in length. The system is presently designed and configured for measuring several gases at the same time. The DOAS system is based upon Beer-Lamberts absorption law. It states the relationship between the quantity of light absorbed and the number of molecules in the light path. Because every type of molecule, every gas has its own unique absorption spectrum properties, or fingerprint, it is possible to identify and determine the concentrations of several different gases in the light pass at the same time.

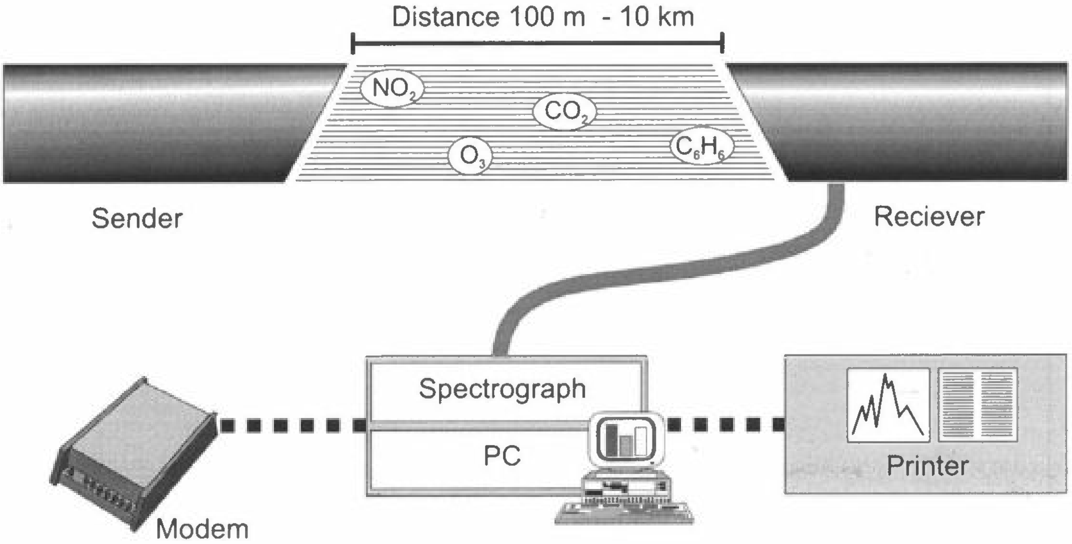


Figure 19: The principle of a DOAS instrument.

The DOAS has been applied to measure path/line integrated (average) concentrations of SO_2, NO_2, ozone, toluene, benzene and some other specific gases in the urban atmospheres. The DOAS provides a rapid, continuous measurement of the different calibrated gases. The data can be transferred to a central computer for treatment and presentation. The disadvantages are the relatively high price.

4.3.12 Meteorological measurements

Meteorological data are normally collected along 10 to 100 m tall towers. In some cases meteorological data are also needed for higher altitudes. In this case weather balloons or aircraft measurements are used.

The surface layer data which are most important for air pollution studies and for explaining the air quality that is being measured are most often collected along a tower using an automatic weather station. These instruments are currently being used in urban area investigations, for industrial air pollution studies included impact from power plants, in most large field studies, in remote areas and in complex terrain studies. Meteorological "surface data" such as winds, temperatures, stability, radiation, turbulence and precipitation are being transferred to a central computer via radio communication, telephone or satellite.

One of the more difficult parameter to obtain on a routine basis is the height of the boundary layer as a function of time. This height is often related to and referred to as the mixing height. These data have to be collected from radiosonde observations, or they can be estimated using meteorological models including boundary layer modelling or description.

When air quality models are being applied for concentration estimates, for exposure modelling, for preparing information and forecasting and decision making purposes, meteorological input data from the boundary layer are crucial.

Continuous measurement of meteorology using Automatic Weather Stations (AWS) requires sensors for at least the most important parameters such as:

1. Wind speeds,
2. wind directions,
3. relative humidity,
4. temperatures or vertical temperature gradients,
5. net radiation,
6. wind fluctuations or turbulence,
7. atmospheric pressure.

An example of an AWS is shown in Figure 20.

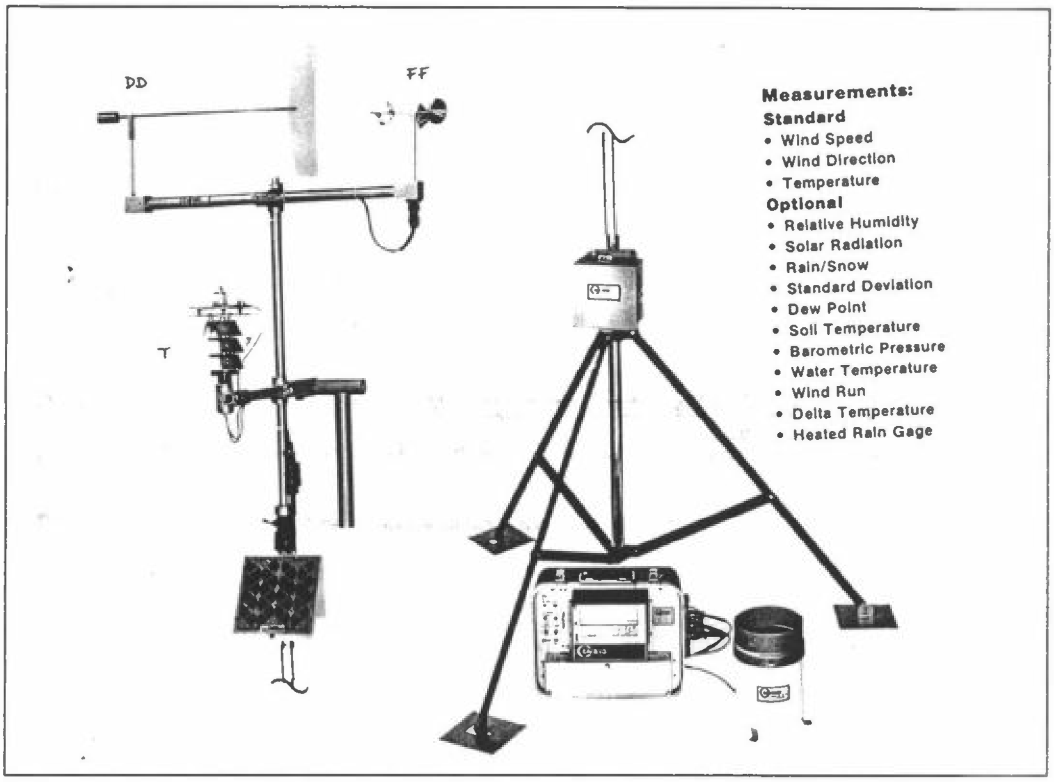


Figure 20: An Automatic Weather Station

From the continuous measurements of winds the following statistical information should be extracted:

* Wind frequency distributions of directions (wind roses) and wind speed for each month and for seasons, for individual stations.
* Average diurnal wind patterns (land sea breeze).
* Time evolution of winds during selected air pollution episodes
* Local wind vs. large scale (synoptic) wind (if geostrophic winds are available)
* Stability and mixing height from available information (temperature measurements and radiosondes)
* Turbulence (σ_u/u) if available
* Frequency distribution of a selected "dispersion parameter"
* Joint frequency distributions of wind direction, wind speed and a "dispersion parameter".

4.4 Chemical analysis

4.4.1 SO_2 analysis by the use of ion chromatography

Ion chromatography is a robust and precise method. It is easy to run and maintenance with very little sample preparation and the consumption of chemicals are low. Overall running costs are low but the investment costs are higher than for the other method.

4.4.2 SO_2 analysis by the barium perchlorate-Thorin method

This method involves the use of many different chemicals, a cation exchange column and a photometer. The method is labour intensive, running costs are relatively high due to the consumption of the chemicals but investment costs are not as high as for the ionchromatograph.

4.4.3 NO_2 analysis

NO_2 can be analysed by ion chromatography which is an easy method to run, but it might cause some interference problems. The most common analysis method is by the use of a spectrophotometric detector. This method is also easy to run and maintenance with very little sample preparation and the consumption of chemicals is low. Overall running costs are low and analysers are available in a wide range of prices.

4.4.4 PM_{10}

Particles are collected on teflon filters on the same filter holder as used for SO_2 sampling (TAC-method). The filters are weighed before and after the sampling. The weighing must be carried out in a room with constant temperature and humidity and the filters must be conditioned by storing in the room before weighing.

4.4.5 Lead

Lead is collected on the same filters that are used for PM_{10}. Lead can be prepared by boiling in sulphuric acid. An easier way to prepare the samples is by the use of closed digestion vessels and a microwave oven. The solution is analysed by atomic absorption. The use of a graphite oven will improve the detection level.

4.4.6 VOC analysis

VOCs are analysed in the laboratory on a gas chromatograph with a thermodesorption unit.

A flame ionisation detector (FID) can be used for the analysis of many organic compounds but is vulnerable for interference in complex matrixes.
A mass spectrometer detector (MS) can detect all kinds of organic compounds with very few interference problems. The MS can also be used for identification of unknown compounds.

4.4.7 Analysis of (persistent) organic pollutants

Analysis of organic pollutants (PAH, dioxins, pesticides etc.) are relatively labour intensive and the consumption of chemicals is quite high. The procedure for sample preparation and analysis could normally be described in five steps:

- Extraction of filters,
- removal of interferences/acid wash,
- chromatographic rinsing,
- volume reduction,
- GC/MS analysis.

For some of the pollutants it could take as much as a week from the arrival of the sample in the laboratory until the analysis is completed.

4.4.8 Analysis of precipitation samples

pH and conductivity

pH and conductivity are measured directly in a portion of the sample by the use of pH- and conductivity electrodes. The samples are checked against a number of standards and control samples.

Analysis of anions in precipitation

Sulphate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) can all be analysed by ion chromatography. If no ion chromatograph are available, sulphate can be analysed spectrometric by the barium perchlorate-Thorin method, nitrate by the spectrometric Griess method and chloride by the mercury thiocyanate-iron method. The use of an ion chromatograph simplifies the analysis since all anions are determined in the same run. The chromatographic method is much less labour intensive than the other methods, the consumption of chemicals are much lower and it gives just as good results. Overall running costs are low but the investment costs are higher than for the other methods.

Analysis of cations in precipitation

Ammonium (NH_4^+), sodium (Na^+), potassium (K^+), calsium (Ca^{2+}) and magnesium (Mg^{2+}). can all be analysed by ion chromatography. Alternatively, the metallic cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) can all be analysed one by one with atomic absorption and ammonium (NH_4^+) by the indophenol blue method. By the use of ion chromatography, all cations can be analysed in one run. The chromatographic method is less labour intensive than the other methods.

Analysis of heavy metals in precipitation

Heavy metals can be prepared by boiling in sulphuric acid. An easier way to prepare the samples is by the use of closed digestion vessels and a microwave oven. The solution is analysed by atomic absorption. The use of a graphite oven will improve the detection level.

4.5 Data retrieval and data handling systems

4.5.1 Data storage and transfer

At site there is a need for a data acquisition system (DAS) to receive the measurement values emitted by one or several gas or dust analysers, meteorological sensors or other parameters. These parameters must be stored, 5 min. and hourly average, and transmitted to a central micro computer via modem and telephone lines.

The storage time must be several days or some weeks in case of problems with modem, transmission lines or central computer.

The DAS-system should also consist of logic outputs remotely controlled for external zero and span solenoid valves.

4.5.2 Software

The micro computer in the central room must be able to receive the data transmitted by several stations equipped with monitors and DAS.

The software must manage acquisition edition and storage of the data issued by DAS. It operates with a PC compatible micro computer. It is used particularly for managing data from atmospheric pollution work stations, optionally linked to the central station by phone hook-ups in the context of the atmospheric pollution control networks.

Configuration

The configuration of the software can be totally determined by the operator (station names, parameter names, units, adjusting scale, automatic calibration, etc.)

Acquisition

- Acquisition of 1 minute integrated values or of average 1 hour values.
- Display of operating alarms, limit overshoots etc.
- Possibility of receiving meteorological parameters (wind speed and direction, temperature, pressure, humidity, etc.) with dominating wind calculation.

Files facilities

- One hour (stored on harddisk) data files available for external use by the operator

Edition

- Choice of display, on the micro computer screen, of the 5-minute integrated values and average 1 hour values:
  - a) for all the measurements of one station
  - b) for one specific measurement of one station.
- Overall daily display of 1-hour average stored values, including status.
- Continuous printing every 1 min., 15 min., 30 min. or 60 min. of all parameters.
- Printing of **daily report**, per station or per channel of hourly average values including validation criteria; mini, maxi, daily average values and number of exceeding threshold values.
- Printing of **monthly report**, per station of per channel of daily average values including validation criteria; mini, maxi and average monthly values and number of exceeding threshold values.
- Display and/or printing of **daily histogram** per parameter of hourly values with validation criteria; mini, maxi and average daily values, programmed threshold values.
- Display and/or printing of **monthly histogram** per parameter of daily average values including validation criteria; mini, maxi and average monthly values, programmed threshold values.

Calibration Operation

Cycle for zero and span remote control, programmable for each channel.
Automatic calibration for each channel on the 24h cycle basis.
Calibration report.

The data must be made available for the main user.

4.6 Quality Assurance (QA)

Data quality assurance (QA) is an important part of data acquisition and data storage procedures. The data quality objectives for the monitoring network should be:

- a high data rate, sufficient to ensure acceptable temporal and seasonal representativeness
- the data capture should be evenly distributed throughout the year, dependent upon site characteristics and pollutants
- the data prepared for storage should be accurate, precise and consistent over time
- the data must be traceable to accepted measurement standards.

A typical performance scheme for a complete measuring cycle applied to air quality sampling (discontinuous/manual method) is shown in Figure 21.

Monthly data capture rates (given in percent) should be reported in the data presentation reports. The average goal should be ~95% accepted data.

4.6.1 QA at site

The need of QA undertaken at the measurement site varies with the type of equipment used. Passive samplers need only a written protocol, while a complex monitoring station needs protocols, calibration gas cylinders and zero air generators. Different kinds of calibrators may also be needed to make ozone and dilution of other gases.

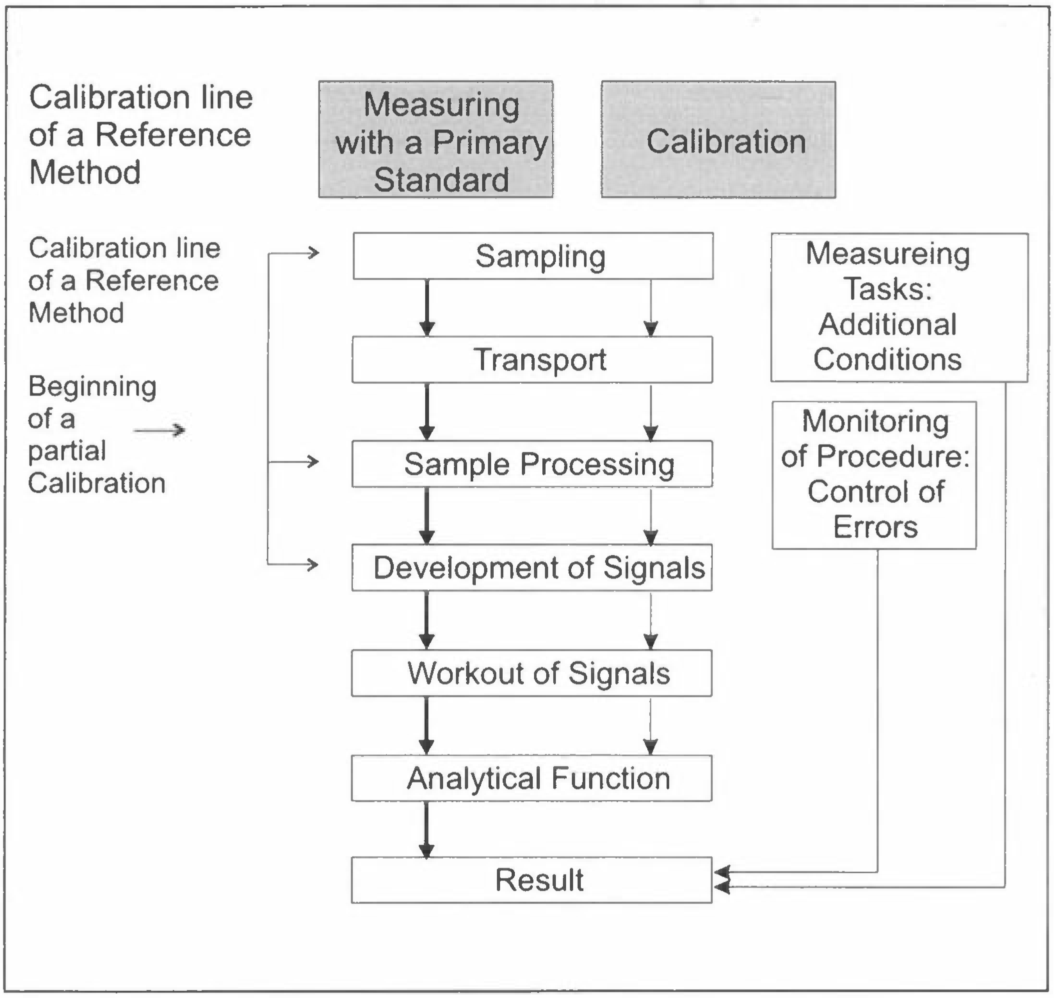


Figure 21: Performance scheme for a complete measuring method.

The gas blenders should be able to dilute gases from verified high concentration table gases to working gas level to make a multipoint calibration of monitors. The gas blenders are also used to control the concentration of the working gas cylinder. This is normally undertaken at a central laboratory. Rotameter to control the air flows are needed at the site.

The air quality network sites should be routinely visited once a week by the local site operators (LSO) and serviced every six months by equipment support units (ESU). In case of instrument breakdown or other site problems, the LSOs have to undertake non-routine site visits. The frequency of such non-routine visits provide a useful indication of the overall smooth running of the network.

4.6.2 Network calibration

A network QA is performed as a total calibration or intercalibration, dependent upon how the network is operated. This part of the QA system must be performed by the central monitor laboratory or by a reference laboratory. These controls should be undertaken regularly in 5-months or 6-months intervals. The purpose of such (inter)calibration is to

- ensure consistency of the measurements in the network
- determine the accuracy and precision of the data
- identify deviations from standard operation procedures (SOP)
- investigate systematic measurement
- check the integrity of the site infrastructure

The tests that are undertaken include a number of performances such as

- accuracy
- response times
- noise levels
- linearity
- efficiency (of NO_2 converters, HC "kickers", etc.)
- integrity of the sampling system

4.6.3 Routine controls at the reference laboratory

Well defined control routines should be developed and defined in standard operational procedures including
- questionnaires,
- forms and schemes,
- control routine check points,

To measure air volumes the reference laboratory must also have available wet gas meters including flow rates of 3 and 20 litres/min. A good calibrated pressure and temperature device is also needed.

There is a need for a zero air generator which has the capability of delivering air to gas blenders and ozone calibrators. The air must be cleaned for all components and must be free from water vapour.

5. Meteorology

The weather on all scales in space and time acts on the transport and dilution of air pollutants and plays different roles on the air quality that we measure and feel (Figure 22).

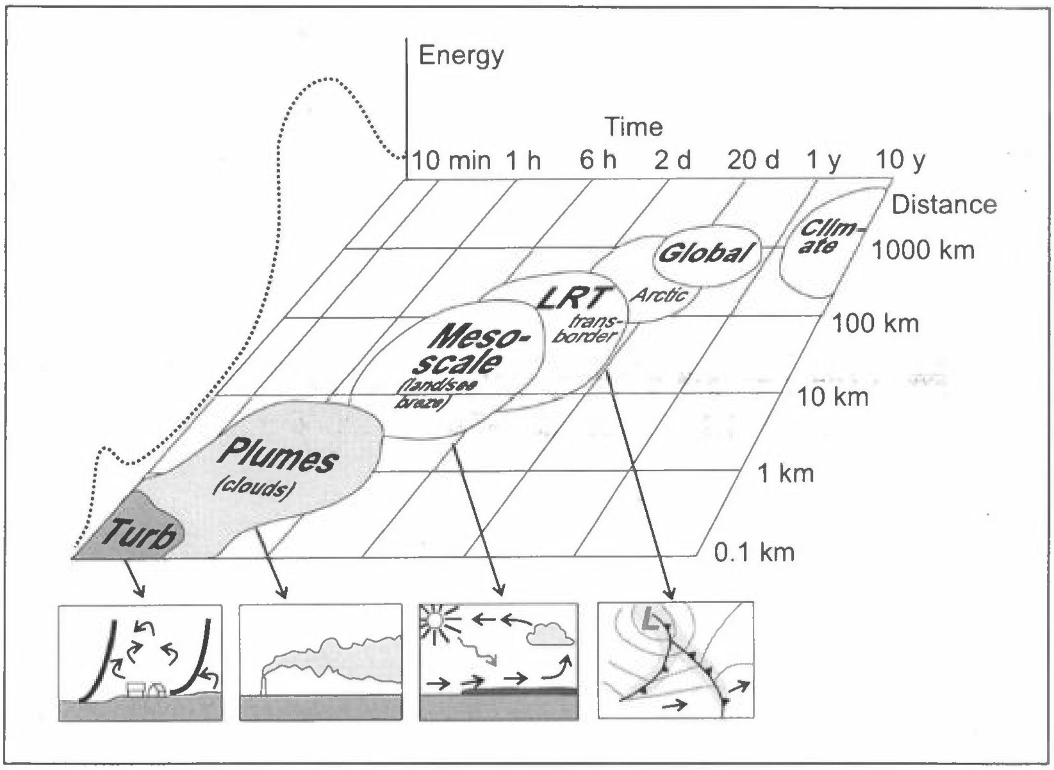


Figure 22: Meteorological scales in space and time.

Meteorology specifies what happens to a plume (or puff) of air pollutants from the time it is emitted from its source until it is detected at some other location. The motion of the air dilutes the air pollutants emitted into it. Given a known emission rate, it is possible to calculate how much dilution occurs as a function of meteorology or atmospheric conditions, and the resulting concentrations downwind of the source. This will require some basic knowledge of meteorology and its effects on the dispersion of air pollutants.

First of all a brief introduction to the composition of the atmosphere and the characteristics of large scale weather phenomenon will be given.

5.1 The atmosphere

The earth's surface is a boundary on the domain of the atmosphere. Transport processes at this boundary modify the lowest 100 m to 3000 m of the atmosphere, creating what is called the boundary layer (Figure 23). The reminder of the air in the troposphere is loosely called the free atmosphere.

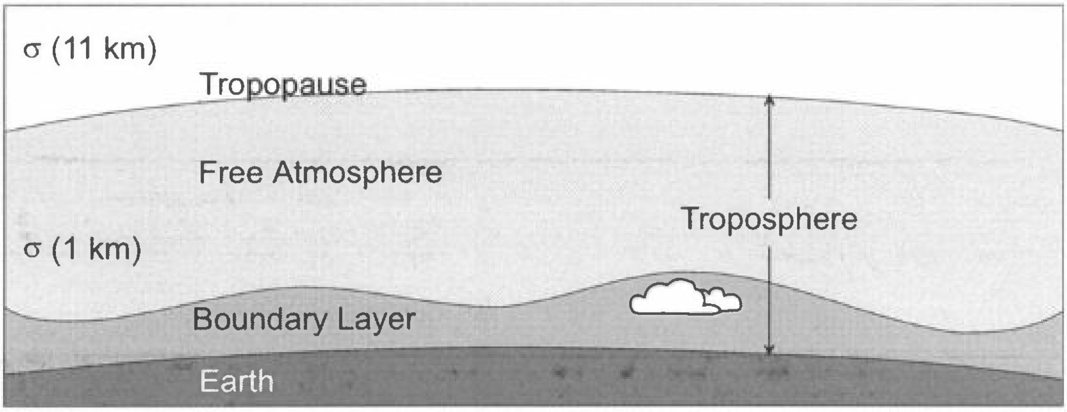


Figure 23: The troposphere can be divided into two parts: a boundary layer (shaded) near the surface and the free atmosphere above it.

The height of the troposphere varies with latitude and is highest at the Equator. Normally only the lowest couple of kilometres are directly modified by the underlying surface. The boundary layer can be defined as the part of the atmosphere that is directly influenced by the presence of the earth's surface, and responds to surface forcing on a time scale of about an hour or less. These forcings include frictional drag, terrain induced flow modifications, evaporation and transpiration, heat transfer and pollutant emission.

The boundary layer thickness is quite variable in time and space, ranging from a few tens of meters (at night time with low wind speeds and winter conditions) to hundreds of meters to a few kilometres. Diurnal variations is one of the characteristics of the boundary layer over land. The free atmosphere shows little diurnal variation.

Local wind and temperature patterns play a significant role to the dilution of pollution. The transport of pollutants emitted into the atmosphere is a function of the local (average) wind direction. The dilution of pollution is mainly a function of wind speed and turbulence. These factors are influenced by topography which channels the wind, vegetation, radiation and radiation balance (stability) which is a function of the vertical temperature profile.

The transport of the emitted air pollution is directed along the trajectory of the air parcel in which the pollutants were emitted. The trajectory is a function of wind direction and wind speed in the wind field. The dilution of pollutants is a function of the atmosphere's turbulent conditions, which are presented by a 3-dimensional variation in wind direction and wind speed. Turbulence is usually defined by fluctuation of the wind with spatial dimensions less than the pollutant plume.

The variation of wind on all scales is the most important factor deciding the air pollution concentration at a receptor location. The wind observed at a certain receptor is the sum of several effects:

- large scale wind patterns (geostrophic)

- friction (roughness change)
- thermally driven local winds
- radiation balance
- topographical features (deformation, channelling ...)

The next chapters give a short introduction to meteorology and the influence of different meteorological factors on the transport and dilution of air pollution.

5.2 Large scale wind patterns

Wind is a result of an equilibrium produced by pressure, Coriolis and friction forces. The pressure forces are caused directly by the existence of high and low pressure regions in the atmosphere. In the Northern Hemisphere the air blows counterclockwise around low pressure centres while in the Southern Hemisphere the air blows clockwise. Weather maps show regions of high and low pressure and also denote wind direction and wind speed (Figure 24).

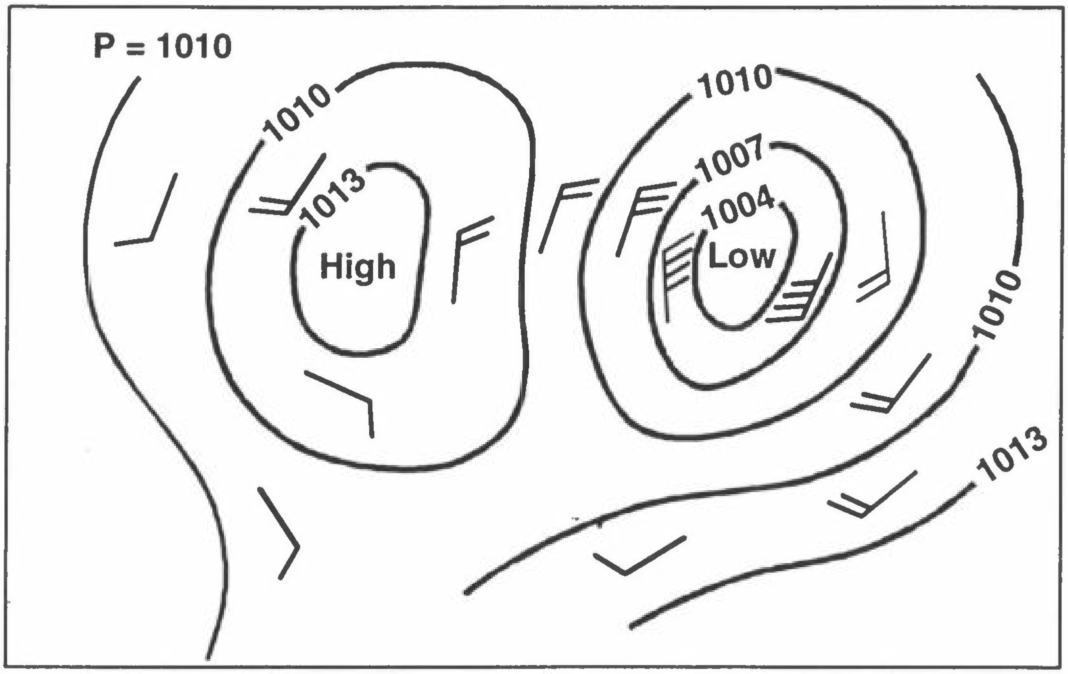


Figure 24: Typical pressure pattern and associated wind field (Northern Hemisphere).

High pressure regions are called anticyclones and these are often the source of temperature inversions. An inversion limits the atmosphere's potentiality for dilution of pollutant emissions.

Near the earth's surface, the friction force acts upon the wind. This force causes a change in wind velocity and wind direction.

5.3 Terrain induced air flow

During the diurnal circulation in mountainous regions, three-dimensional circulations can form within and just above the valleys. A brief description of the cross-valley-axis flow (anabatic/katabatic slope winds), the along valley-axis-flow (mountain/valley winds), and the combined three-dimensional mountainous circulation is presented below.

5.3.1 Wind and flow

Air flow, or wind, can be divided into three broad categories: mean wind, waves and turbulence (Figure 25). Each can exist separately, or in combination with any of the others. Air flow is responsible for the transport of quantities such as moisture, heat, momentum, and pollutants. In the horizontal these transports are dominated by the mean wind, and in the vertical by turbulence.

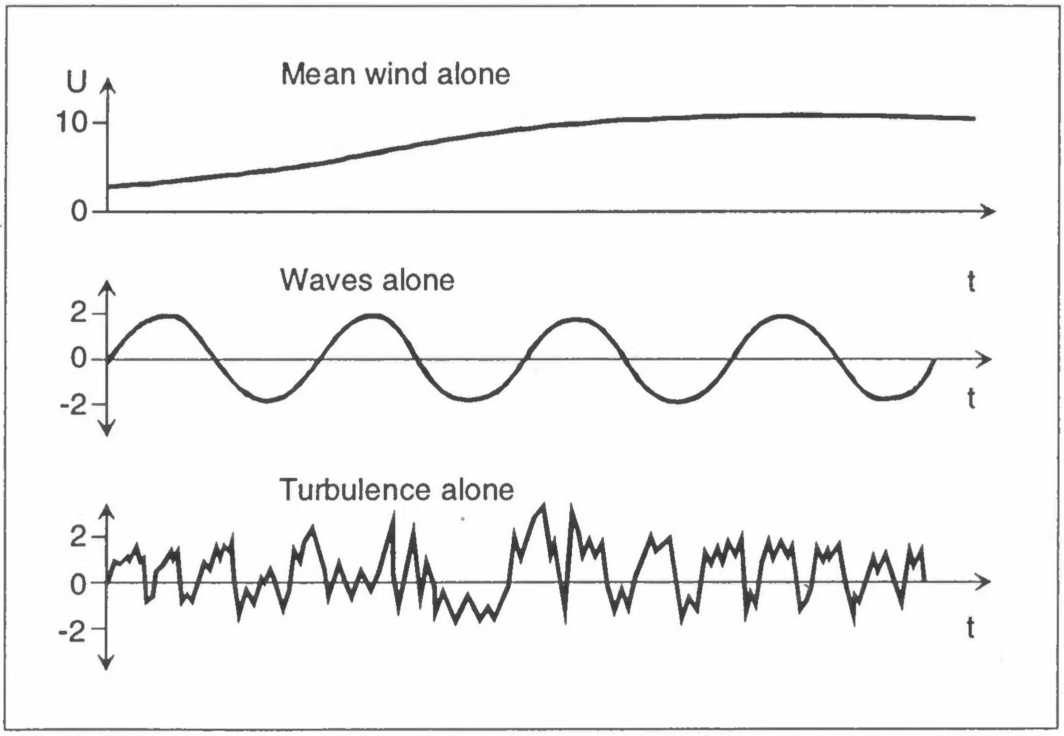


Figure 25: Idealised picture of contributions to instantaneous wind speeds from of (a) Mean wind alone, (b) waves alone, and (c) turbulence alone. U is the component of wind in the x-direction.

Horizontal winds on the order of 2 to 10 m/s are common in the boundary layer. Friction causes the mean wind speed to slow down near the ground. The effect of terrain roughness on the horizontal wind speed profile is presented in Figure 26. Vertical mean winds are much smaller than the horizontal components, usually on the order of millimetres to centimetres per second. Near the ground it is almost zero. The vertical wind velocity normally increases with height up to the middle of the boundary layer. The vertical wind velocity is very dependent on atmospheric stability.

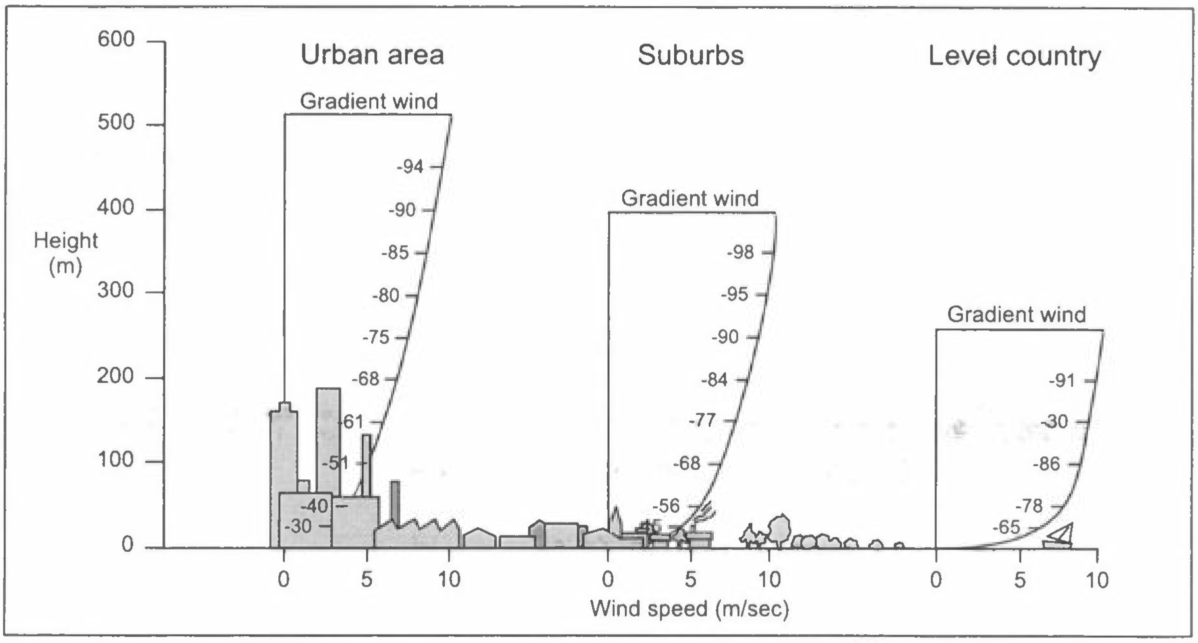


Figure 26: Effect of terrain roughness on the wind speed profile. The depth of the affected layer decreases with decreasing roughness (i.e. urban area versus suburban area).

5.3.2 Mountain and valley winds

An idealized evolution of the diurnal cross-valley circulation is shown in Figure 27.

During night, radiative cooling of the mountain sides cool the air adjacent to the surfaces, resulting in cold downslope or katabatic winds. These winds are normally very shallow (2 to 20 m), and the normal velocities are within the order of 1 to 2 m/s. Above the valley floor drainage flow is a gentle return circulation of upward moving air that diverges toward the ridges. The chilled and heavy air flows into the valley and collects as a cold pool. Although some of the cold air flows down the valley axis, some can remain in the valley depending on the topography. The resulting pool is often stably stratified throughout its depth, and is sometimes called a valley inversion. The potential temperature profile indicate the shallow inversion layer that started to build up in the valley bottom during the night. The radiative cooling of the ground continued throughout the night creating a deep cold pool throughout the valley. Pollutants emitted into this inversion can build to high concentrations because of very slow dispersion in the vertical, and can be hazardous to people, animals, and plant life on the slopes.

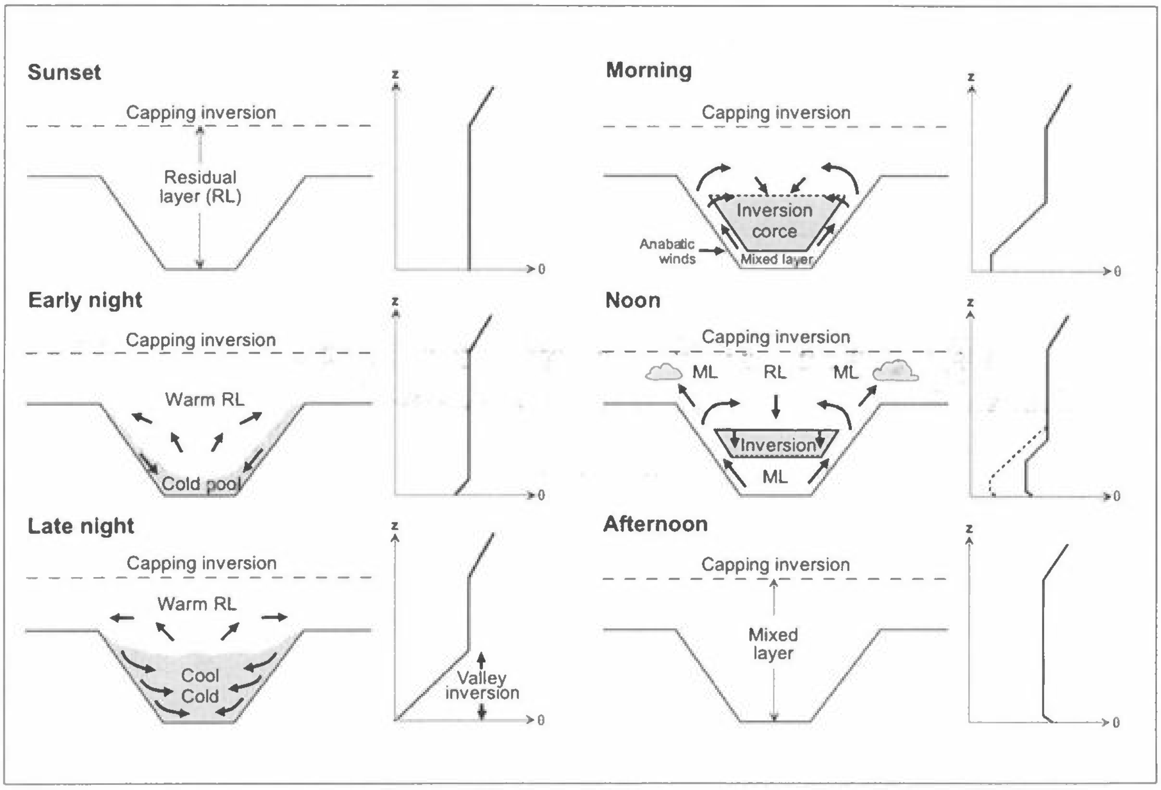


Figure 27: Idealized evolution of the cross-valley circulation during a diurnal cycle.

During the sunny hours after sunrise, the incoming solar radiation will warm the mountain/valley sides and the air in contact with it faster than the air at some distance from the slope. This differential heating sets up a circulation which is akin to the sea breeze and is called the anabatic winds. Because of this instability in the lower layers of air set up by the differential heating, the warm air will stream toward and up the valley sides. The solar heating of the valley bottom and the valley sides result in a shallow layer just above ground where temperature decrease with height (unstable layer). Above the shallow layer is a thin well mixed layer and the reminder of that is left of the night time inversion layer. The depth of the well mixed-layer increase during morning in accordance with the radiation heating of the valley floor and -sides, with a resulting decrease of the stably stratified layers. Above the valley inversion there is a gentle convergence and subsidence. As this warmed air leaves the valley floor, the remaining pool of cold air set up during night sinks to replace it. Eventually, the pool of cold air is completely eliminated and the mountainous area is now covered by warm air masses.

5.3.3 Drainage winds

At night, the cold winds flowing down the valley onto the plains are known as mountain winds or drainage winds. Depths range from 10 to 400 m, depending on the size and flow constrictions of the valley. Velocities of 1-5 m/s have been observed and these winds are occasionally intermittent or surging. The return gentle circulation of warmer air aloft is called the anti-mountain wind, with velocities of about half of the mountain wind, and depth of about twice as much (Figure 28a).

During the day, warm air gently flowing up the valley axis is known as the valley wind. This wind consist of a valley-floor component, and sometimes an up-incline component along the ridge tops. The cool, slow return flow aloft is called the anti-valley wind (Figure 28b).

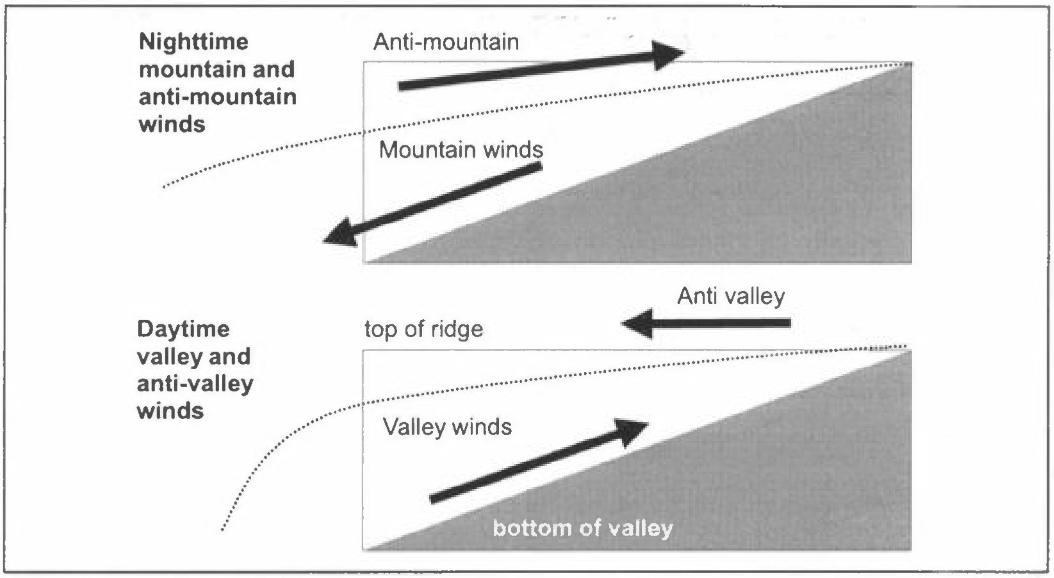


Figure 28: Along-valley winds.
(a) Night-time mountain and anti-mountain winds
(b) Daytime valley and anti-valley winds.

5.3.4 The three-dimensional circulation in mountainous regions

The combined three-dimensional picture of the mountain/valley wind system is shown in Figure 29 and Figure 30. During night the downslope and down-valley winds will converge just above ground, with gentle up-valley winds and divergence aloft.

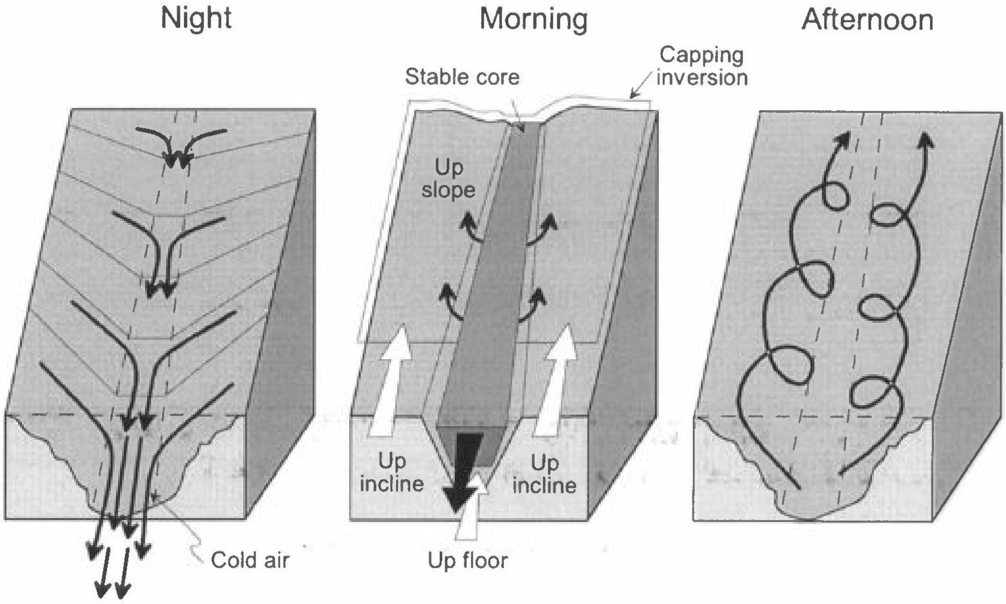


Figure 29: Three dimensional pictures of idealized local mountain circulation
(a) at night
(b) morning
(c) afternoon

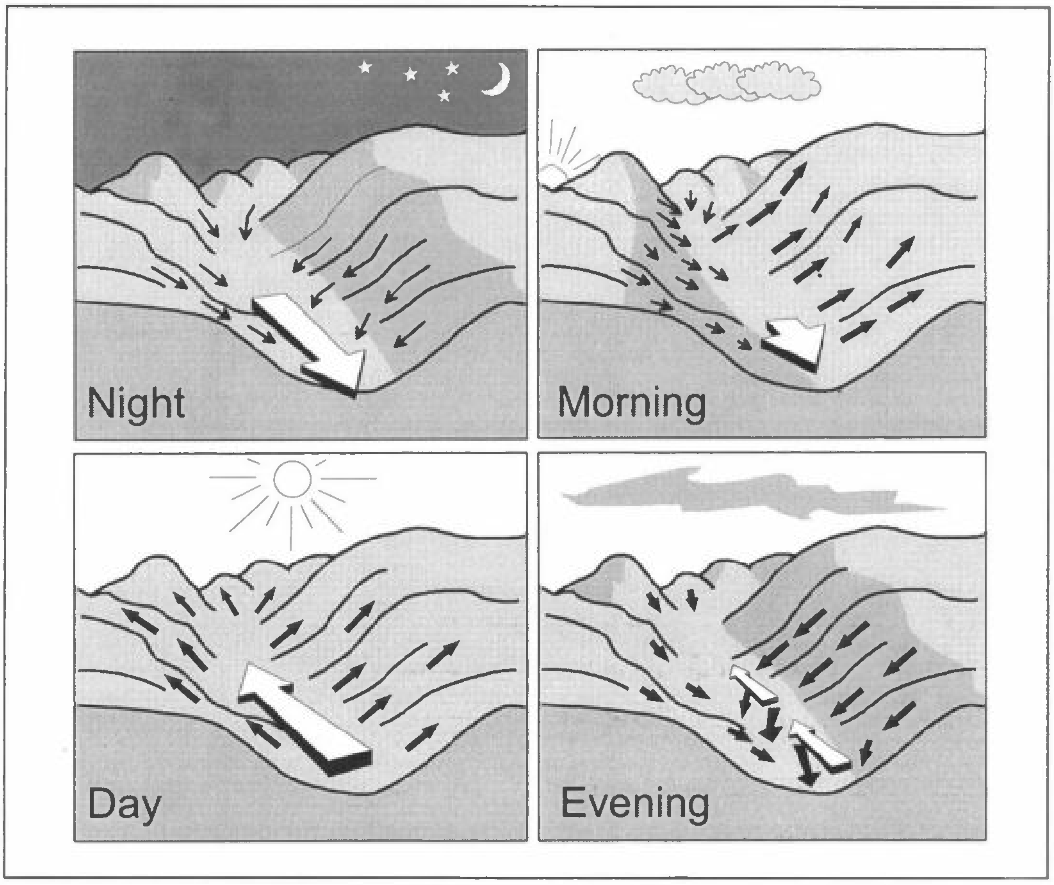


Figure 30: Typical diurnal variations for mountain-/valley winds

If the terrain is such that there are converging valleys, the cooled air will converge in the valley bottoms and accelerate downward through the main valley, with the result that the night wind in such places may be stronger than the day breeze.

On a calm day the mountain and valley winds reveal their presence by cumulus clouds forming over the mountains during the day and dissolving in the evening. As in the case of the land and sea breeze, the mountain and valley winds may be overshadowed by a general wind system.

Knowledge of topography, and hence, the mountain/valley wind system is important for air pollution transport and diffusion in valleys, as most of the low level sources (traffic, heating, etc.) often are located along the valley bottoms.

5.3.5 Sea and land breezes

5.3.5.1 Sea breeze

The large heat capacity of oceans and lakes reduces water-surface temperature change to near-zero values during a diurnal cycle. The land surface, however, warms and cools more dramatically because the small molecular conductivity and heat capacity in soils prevents the diurnal temperature signal from propagating rapidly away from the surface. As a result, the land is warmer than water during the day, and cooler at night. This situation causes sea breezes.

The general feature is that during the morning there is little difference in temperature between land and sea. During mid-morning, however, air begins to rise over the warm land near the shoreline as a result of the solar heating from the sun, and cooler air from the water flows in to replace it. A return circulation (the anti-sea-breeze) aloft brings the warmer air back out to the sea where it descends toward the sea surface to close the circulation. The depth of the sea breeze have been observed to be on the order of 100 to 500 m, and the total circulation depth including the return circulation can range from 500 m to 2000 m.

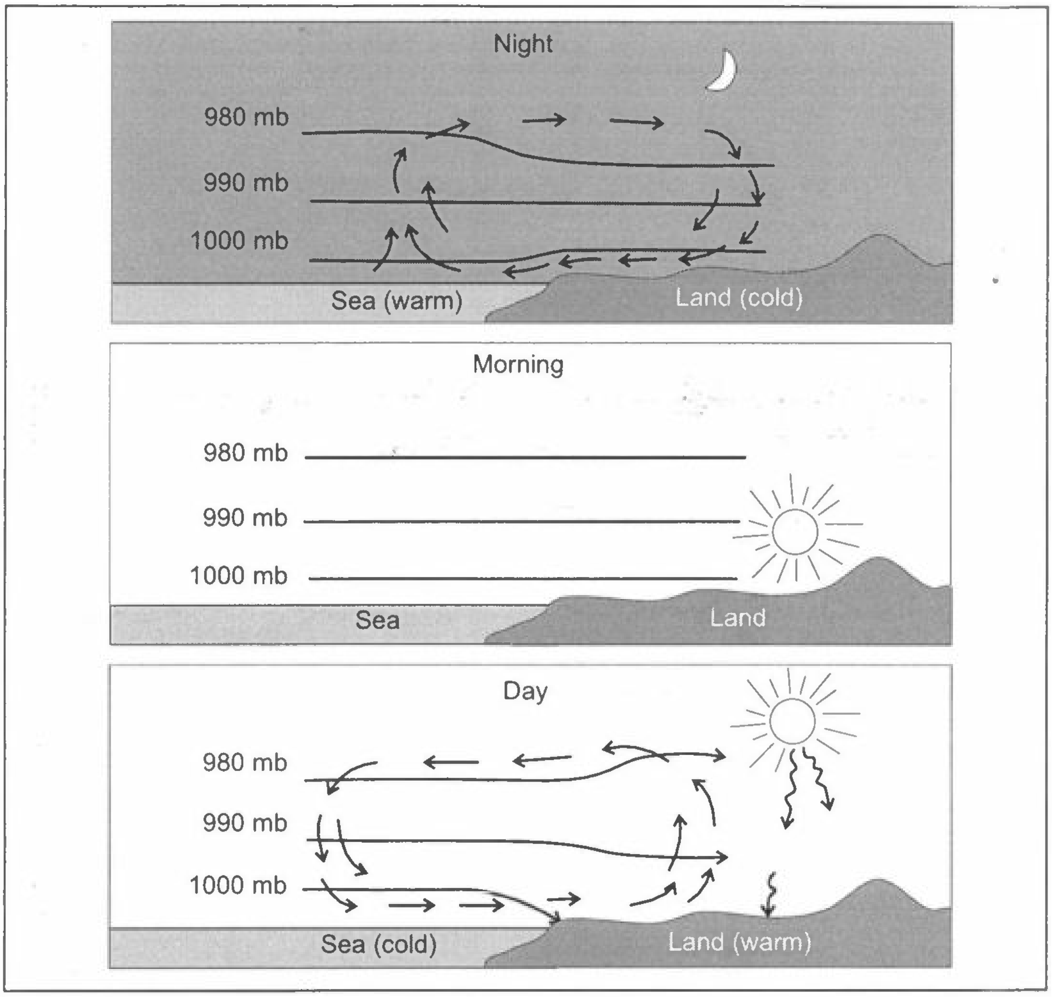


Figure 31: Idealized sea or lake breeze circulation.

5.3.5.2 Land breeze.

At night, land surfaces usually cool faster than the neighbouring water bodies, reversing the temperature gradient that was present during the day. The result is a land breeze; cold air from land flows out to sea at low levels, warms, rises and returns aloft towards land (anti-land-breeze) where it eventually descends to close the circulation.

5.3.6 Deformation and separation of flow

Topographical inhomogenities often result in large spatial variations in both wind speed and direction. The wind direction changes are most pronounced in valleys where channelling is effective. The wind speed also changes as flow passes across hills or obstacles. When the streamlines no longer follow the contour of the hill, the primary flow is said to "separate" (Figure 32). This separation might cause large turbulent eddies to develop behind the hill. If pollutants are released in the turbulent wake zone, high ground-level concentrations may be found.

Flow separation is commonly observed on the lee side of mountains and is especially pronounced to the lee side of sharp crests. The separated regime is characterized by high mixing rates, lower velocities, and reversed eddy flow. Figure 33 summarizes some effects of separation of the boundary layer.

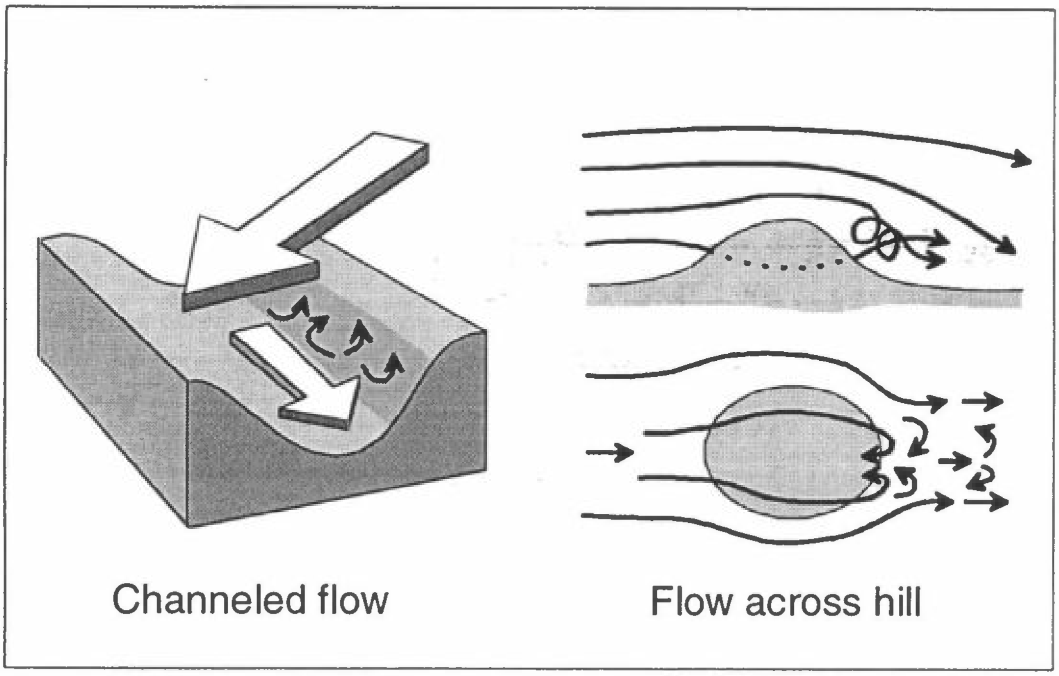


Figure 32: Deformation of flow due to channelling and airflow around and over hills (obstacles).

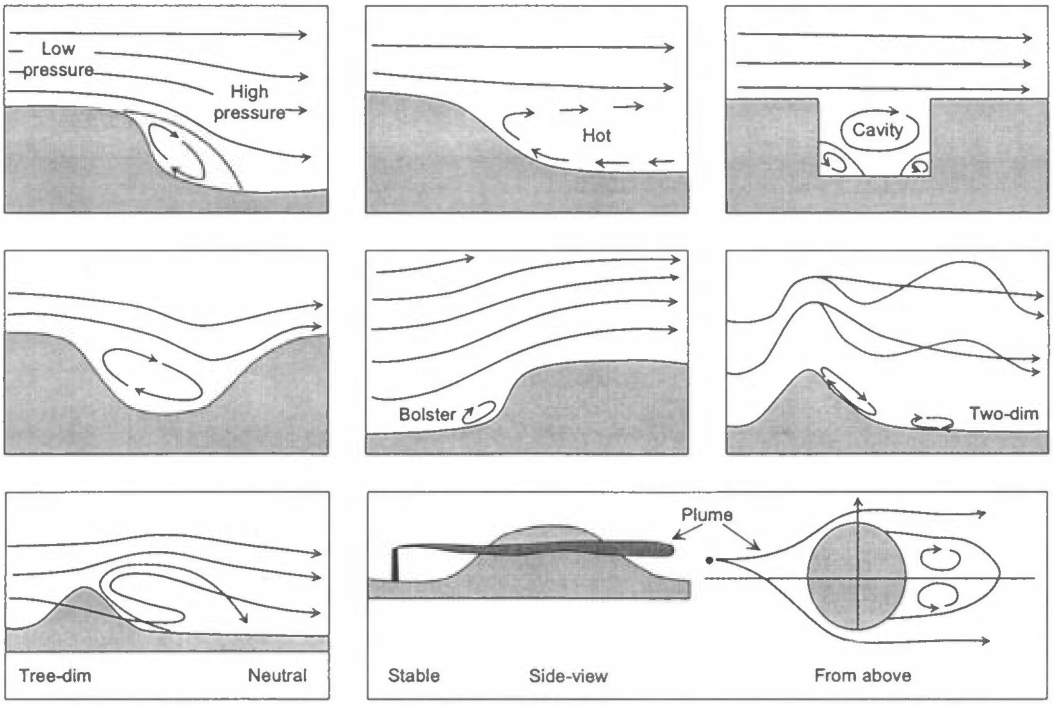


Figure 33: Various aspects of flow separation in complex terrain.

The main aspects are that:

a) In situations where air flows from a low pressure region on a plateau to a high pressure region at lower elevation, separation of the streamlines might occur, sometimes with a small cavity zone close to the lee side of the mountainous plateau with reversed circulations close to the ground.

b) For flow up a slope, heated by sunshine, separation occurs near the top.

c) In a valley with steep cliff sides, or in street canyons, cavity might occur resulting in a very complicated flow.

d) In an actual valley with cross-valley external wind, the flow may be very unsteady; the eddy may fill the valley at one moment and then rejoin near the foot of the wind facing slope, gusting from time to time.

e) Eddies at the foot of the upwind side of a two-dimensional mountain ("bolsters"). In situations with strong winds and weak stability, large amplitude lee-waves or mountain waves might form when the natural wavelength of the air match the size of the hill. Rotor circulations near the ground under the crest of the waves might occur causing a reverse flow at the surface under the rotors.

f) In neutral flow, the air flows around the tree-dimensional hill and up the sides to the top, where it may be separated. The neutral flow over three-dimensional hills is similar to that of two-dimensional hills, except for the wake structure.

g) Stratified flow over a three-dimensional hill. Below the top of the hill the flow tend to move in horizontal planes because of the stratification. At each level the air moves around the hill as if it were a vertical cylinder with a cross-section of the hill at that level. This pattern breaks down in two places: over the top of the hill, and on the lee side where the horizontal flow separates

For air pollution evaluations, the most important feature of the flow separation is the downwind wake effect behind hills and mountains. From observations in the atmosphere and wind tunnel studies the following general features are observed:

- The region of separated or reversed flow may extend up to 10 hill heights downwind (Figure 34).
- The vertical extent of this region might be from a fraction of the hill height, H, to as much as 2H.
- Downwind of the separated flow region the wake region is characterized by a deficit in the mean velocity decreasing down wind, vigorous turbulence within the wake and an average downwind motion.

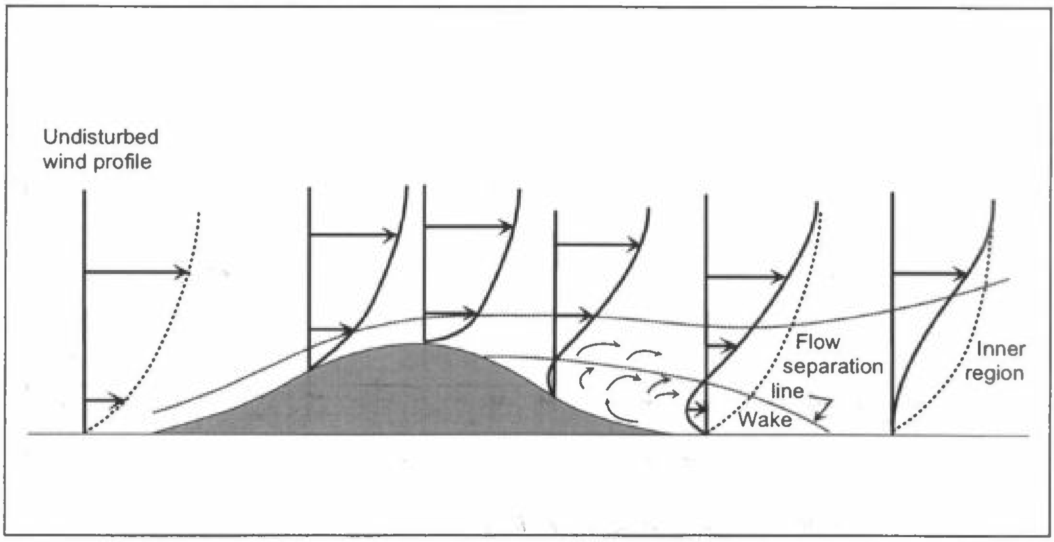


Figure 34: The cavity zone in the lee of a Gaussian ridge.

A similar separation of flow occurs for flow over a building. Figure 35 show the flow pattern around a building. The flow separates to form a large cavity behind the building. Reverse circulations will occur at the surface in the cavity zone. Pollutants emitted from downwind sources in the cavity zone will be transported backwards and up along the building facade. Pollutants emitted in this cavity zone tend to remain there since very poor mixing between the cavity and the main stream occurs.

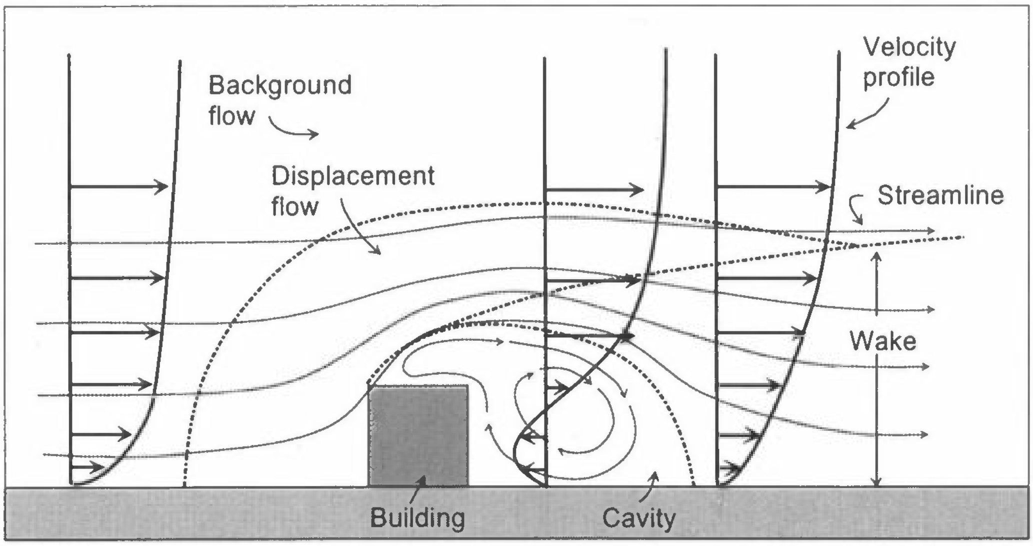


Figure 35: Mean flow around a cubical building. The presence of a bluff structure in otherwise open terrain will produce changes in the wind flow generally similar to those shown here.

Figure 36 shows the evolution of pollutants emitted from an upstream source when the separated cavity and wake behind a building interfere with the plume dispersal. Figure 36a shows what happens when the stack plume is unobstructed by the cavity zone of the building but enter the wake. Downward diffusion increases by mixing occurring in the turbulent wake. In Figure 36b the plume is trapped in the upwind cavity zone of the building resulting in high concentrations on the lee side of the building. It is very important that industrial plant designers are aware of this problem and make sure that stack plumes do not interact with the different flows set up by buildings. An empirical rule of thumb for stacks located at or near buildings is that $H_{stack} \geq 1.5 \ H_{building}$.

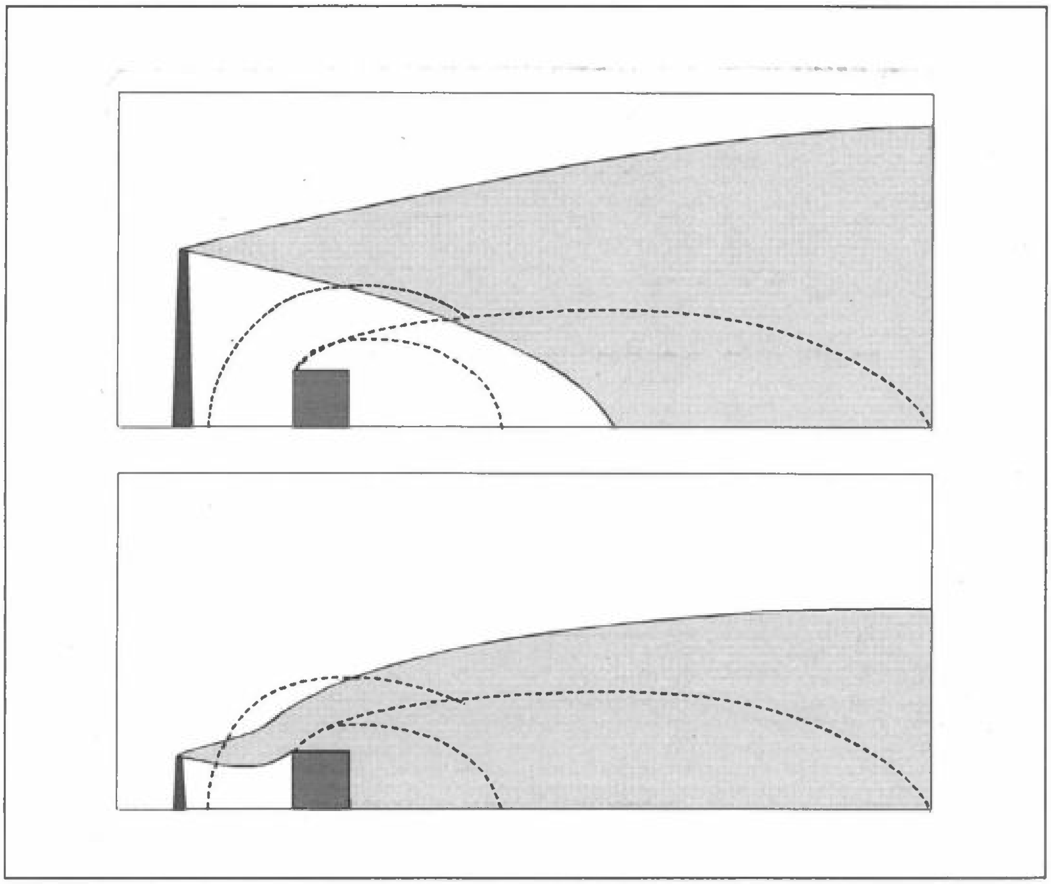


Figure 36: Separation effects on plume dispersion.

5.4 Turbulence

The atmosphere can disperse gases and particulate matter rapidly because it is turbulent. Turbulent flow can be defined as having the ability to disperse embedded gases and particles at a rapid rate. Turbulence is the primary process by which momentum, heat, and moisture are transported into the atmosphere from the surface of the earth and then mixed in time and space.

Turbulence can be visualized as consisting of irregular swirls of motion called eddies. Usually turbulence consists of many different size eddies superimposed on each other. Thus, a continuous hierarchy exists from the largest down to the smallest eddies, with molecular diffusion occupying the bottom of the scale.

The effect of eddy motion is very important in diluting concentrations of pollutants. An air parcel that is displaced from one level in the atmosphere to another can carry both momentum and thermal energy with it. Obviously it will also carry the pollution emitted into the air parcel. Hence, smoke and pollution will be diffused by the turbulent motions in both the horizontal and vertical directions.

The effect of different eddy sizes on a plume is shown in Figure 37.

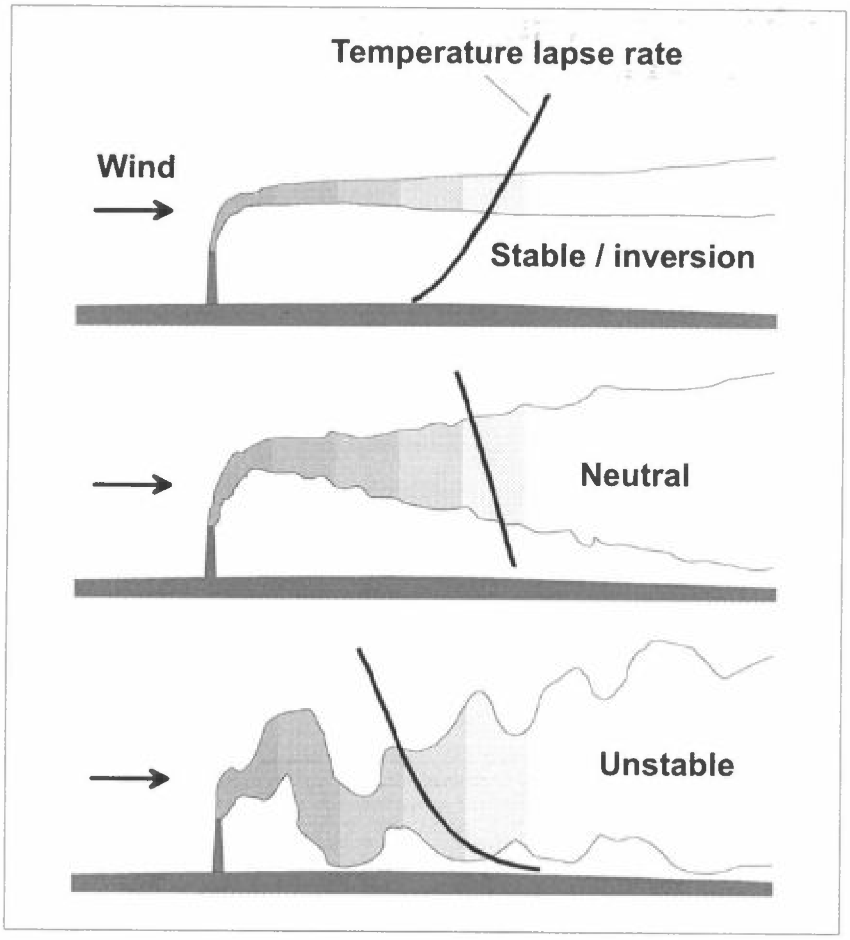


Figure 37: (a) Plume dispersing in a field of small eddies in a stable atmosphere (inversion). The plume will move in a relatively straight line, with gradual increase of its cross section.

(b) Plume dispersing in a field of well defined large eddies (near neutral atmospheric conditions).Turbulent eddies with typical size less than the plume dimension will disperse the plume effectively.

(c) Plume dispersing in a field of large and various sized eddies. This is atypical daytime situation with unstable atmospheric conditions. The dispersed plume will both grow and meander as it moves downwind.

Atmospheric turbulence depends in general on the magnitude of three factors: mechanical effects or the roughness of the ground, horizontal and vertical wind shear, and thermal instability. These factors are described separately in the following chapters.

5.4.1 Mechanical induced turbulence

Frictional drag on the air flowing over irregular ground causes wind shears to develop, which frequently become turbulent. The larger the irregularities, the greater the mechanical turbulence (
Figure 38). The magnitude of the turbulent eddies is a function of surface roughness, elevation above ground and wind speed. The faster the mean wind speed, the greater the contribution by mechanical effects at the ground, with the contribution decreasing as height increases. Also, obstacles like trees and buildings deflect the flow, causing turbulent wakes adjacent to and downwind of the obstacle. These types of turbulence caused by air flowing over rough surfaces are called mechanical turbulence.

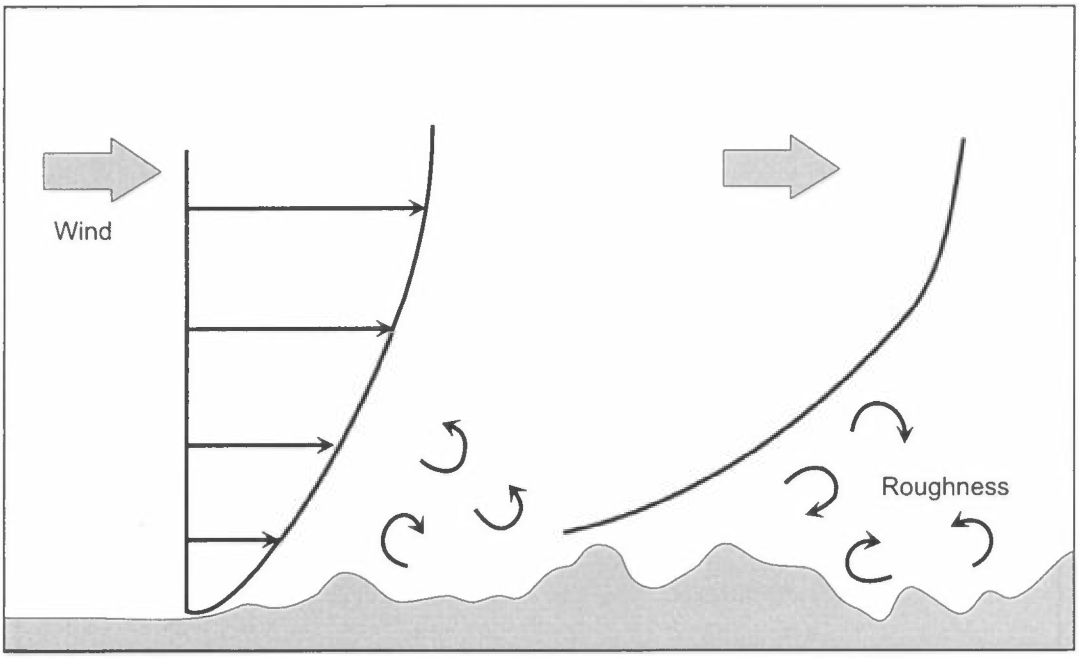


Figure 38: Mechanical induced turbulence (surface roughness).

Mechanical induced turbulence is caused by wind flow over uneven and rough surfaces. Turbulence is generated by mechanical shear forces at a rate proportional to $(\partial u/\partial z)^2$ (the wind speed profile). The wind profile gradient is dependent upon the surface roughness and the stability of the atmosphere. The velocity profile can be described using the power law:

$$\overline{U}_z = \overline{U}_o \left(\frac{z}{z_o} \right)^m$$

where m varies between 0.12 and 0.50, depending on the atmospheric conditions.

5.4.2 Thermally induced turbulence

Convection or thermally induced turbulence is defined as predominantly vertical atmospheric motion resulting in vertical transport and mixing of atmospheric properties. Convective eddies or turbulence arise from hydrostatic instability as the result of surface heating (i.e. solar heating of the ground during sunny days causes thermals of warmer air to rise) (Figure 39). These eddies are largest and occurs at a lower frequency than eddies produced by mechanical turbulence. Note that convective turbulence, unlike mechanical turbulence, is indirectly related to wind shear and strongly related to stability

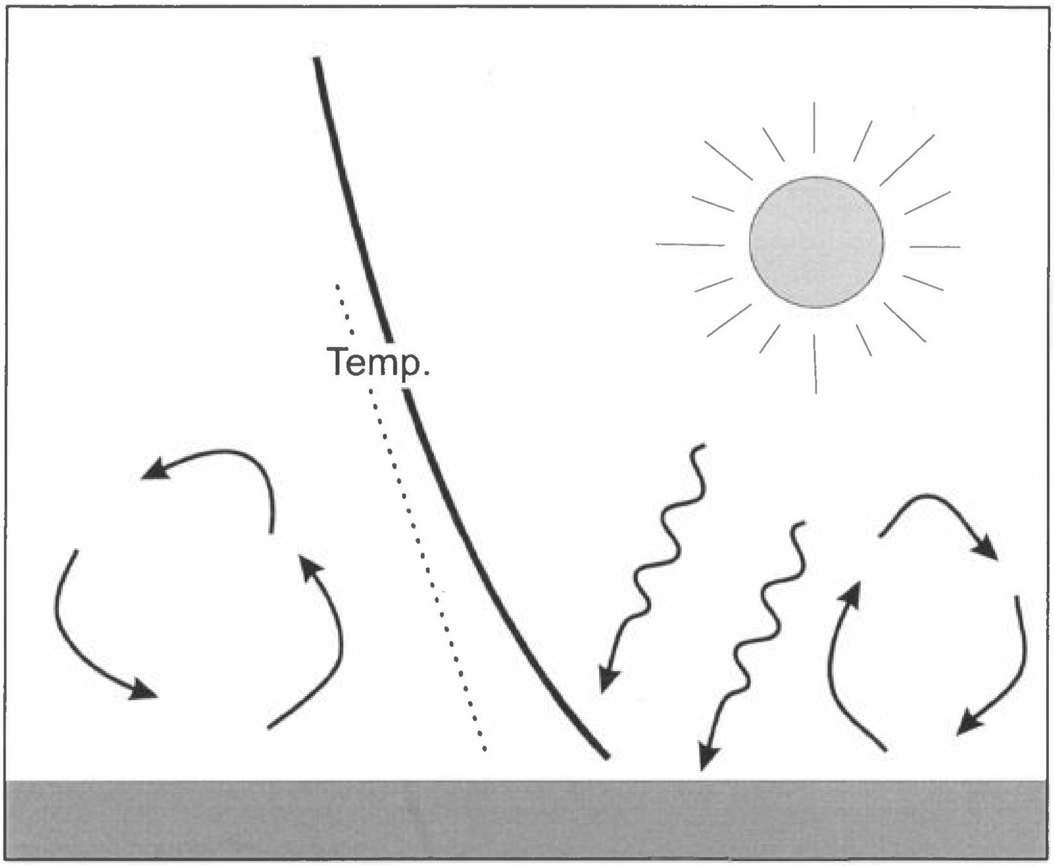


Figure 39: Thermally induced turbulence (solar radiation).

5.5 Atmospheric stability

In its simplest terms, the stability of the atmosphere is its tendency to resist or enhance vertical motion, or alternatively to suppress or augment existing turbulence. Stability is related to both wind shear and temperature structure in the vertical, but it is generally the latter which is used as an indicator of the condition.

The atmospheric stability, or the atmospheric dispersion conditions, can be classified as either unstable (U), neutral (N) or stable (S). A short description of the three individual classes of atmospheric stability is given below and also shown in Figure 40.

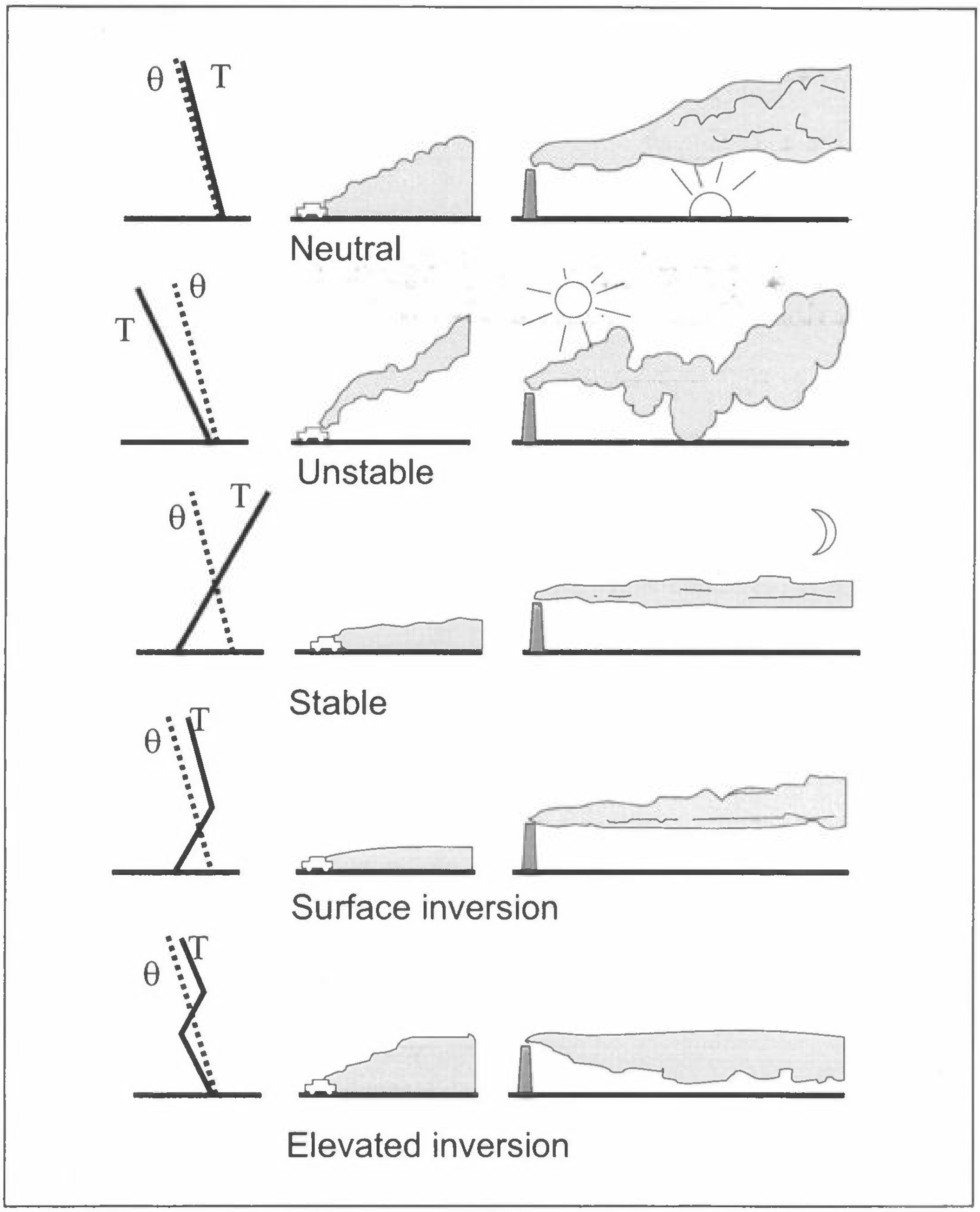


Figure 40: Schematic presentation of the atmospheric stability and the corresponding dilution of air pollutants above ground level.

- Unstable atmospheric stability (U) is common on days with strong solar heating and low wind speed, or when cold air is being transported over a much warmer surface. The sun warms the underlying surface and vertical turbulent eddies are set up causing vertical dispersion of the smoke plume. For emissions at ground level or just above ground level, the concentrations will dissolve quickly. For stack emissions, elevated concentrations may occur at the ground because of the turbulent motion of the lowest level of air.

- Neutral atmosperhic stability (N) occurs at moderate to high wind speeds, usually connected to overcast skies. High wind speeds and good mechanical turbulence/mixing result in good horizontal and vertical mixing of the smoke plume.

- Stably stratified atmosphere (Ls, S) is usually confined to clear nights and winter situations with cooling of the ground and the lower layers of air. In a stably stratified atmosphere the temperature increase with height, and hence, the vertical dispersion is poor. In situations when relatively warm air from the sea is transported over land, the lower level of air will be stably stratified. This result in poor dispersion of the smoke plume both horizontally and vertically. For ground level sources this situation is critical because of poor vertical dilution and hence, enhanced ground level concentrations of pollution. For stack emissions, poor vertical dilution result in high level pollution concentrations being transported far before it touches ground.

6. Air Pollution Modelling

Air pollution dispersion models are used to establish relationships between emissions of air pollutants and the ambient concentrations or air quality. The basic input to these models are information on:

- Emission sources, location, stacks, emission rates,
- physical/chemical properties, topographical features,
- meteorological data, turbulent dispersion
- air quality data, to verify estimates

Information concerning the emission of air pollutants is essential when using source oriented dispersion models (see chapter 6.3). In the following we will discuss how to obtain emission data as input to models.

Meteorological data are essential for calculation of the transport and dilution of air pollutants.

Knowledge of physical properties such as surface roughness, vegetation and topography, and knowledge of chemical reactions, are needed to estimate physical and chemical changes (reactions) that take place after the pollutants are released into the atmosphere.

To verify and test the dispersion models developed or established for a defined area, air pollution measurement data collected in this same area are needed as a platform for comparisons.

In this chapter we will describe how to obtain input data for the emissions, and we will also present a selection of different type of dispersion models available.

6.1 Emission estimates

Emission data are needed for all types of source oriented dispersion models. The main input to the dispersion models are the emission rates. The emissions rates can either be estimated or taken directly from emission measurement data. In the following chapter we will describe some of the methods available for obtaining this information.

Emission rates can be estimated from information on production activity or production numbers. The fundamental equations for emission estimates are:

Emission rate = Activity rate x Emission factor or
Emission rate = Production rate x Emission factor.

where

- activity or production rate relates the amount of fuel used or material produced in the covered time period and is given e.g. in tonnes per year;

- emission factor indicates the amount of pollutant released per unit of activity rate and is given e.g. in kilograms of pollutant per tonne of product.

- emission rate specifies the amount of pollutant generated per unit of time and is given e.g. in kilograms of pollutant per year.

In calculating emission levels, the spatial coverage may relate to:

- point, area, and line sources
- administrative units at different territorial levels
- the whole country

according to the background data used.

In a national emission inventory, two types can be distinguished:

- national total inventories without any spatial resolution
- national spatial inventories on a certain grid system or relating to administrative units of a certain territorial level.

Depending on the circumstances, sources can be treated individually or collectively:

- Individual: Point sources such as power plants, refineries, and airports. Site-specific activity and emission data if possible data can be recorded

- Collective: Sources comprising large numbers of small emitters, i.e. all industrial boilers or those of a certain size are treated as a whole.

Depending on the aims of the inventory and on resources available, analysts must decide to what extent the individual approach is to be applied. Major advantage of this type of procedure will be an essential enlargement of information about spatial distribution concerning both location and amount of emission.

6.1.1 Emission from area sources

Area sources are used to describe sources where geographical distribution is not exactly known and where emissions are small but in large numbers so that they have a significant impact on concentrations. These kind of emissions can be from house heating, traffic, land use etc.. These emissions are normally connected to use of different fuels in an area that is distributed according to population distribution. It could also be used to model emissions of ammonium from agriculture. The area sources in a city have local influence, they are linked to consumption and emission factors are needed

6.1.2 Emission from stationary point sources

Activity data should be linked to the emission generation process as closely as possible. Two examples can be given

- for emission from power plant combustion of certain fuels; (1) fuel input instead of electricity output should be used, and (2) energy units instead of mass units should be used. Consequently, determination of appropriate heat values of fuels may be necessary where fuel data are available in mass units only;

- for combustion related emissions in general: emission characteristics vary from fuel to fuel and hence activities should be reported in this way, instead of using a total energy approach.

One must pay special attention where both combustion and fuels and processing of materials may have effects on emissions. Fuel mixture as well as specific energy demands may change over time. As a consequence, both fuel input and product output need to be accounted.

Whenever point sources are estimated individually, the estimated sum of the activity represented by these sources should be subtracted from the estimated collective activity. This is to avoid double-counting the individually considered point sources when estimating the rest of the source activity emissions (the collective approach).

As in the case of point sources treated individually in the accounting for processes with combustion, attention should be paid to avoid double-counting of energy consumption statistics. Reference activity data may be available from public and private statistics, institutions or research projects. Information on fuels should include non-commercial fuels and wastes used for energy generation.

6.1.2.1 Emission factors - point sources

In most cases emission factors from literature are not fully described. Consequently, the user should thoroughly check whether the conditions under which such factors have been established are well understood. The following questions can be addressed:

- What range of boiler size is represented?
- Is refinery throughput referred to in terms of crude oil or total oil?
- Does the refinery source include gasoline dispatch or not?
- Regarding process with combustion referred to in terms of material, are combustion related emission included or not?
- Is the emission factor controlled or uncontrolled?

In deciding whether to use emission factors from an outside reference for a given country, one must check whether comparable conditions exist, e.g. regarding raw material characteristics, type of process, or operating conditions. Application of per capita coefficients cannot be recommended because such parameters reflect very specific socio-economic conditions.

As an example the estimate of SO_2-emissions using available emission factors is dependent upon several conditions. Parameters influencing the SO_x-emission factors might be:

- sulphur content of the fuel;
- sulphur retention in ashes;
- control efficiency, free gas desulphurization;
- type of processes.

Examples of emission rates of SO_2 from various processes are roughly:

Burning of coal : *lb* SO_2/ton = 38 x per cent sulphur by weight.
Burning of fuel oil : *lb* SO_2/1000 gal = 159 x per cent sulphur by weight.
Diesel engine exhaust : *lb* SO_2/1000 gal = 40, based on 0.3% S in oil.
Sulphuric acid manufacture : 20-70 *lb* SO_2/ton of 100% ACID.
Copper smelting[a] : 1250 *lb* SO_2/ton of concentrated ore.
Zinc smelting[b] : 530 *lb* SO_2/ton of concentrated ore.
Sulphite paper making[c] : 40 *lb* SO_2/ton of air-dried pulp.
Coke drying : 0.25 *lb* (SO_2 + SO_3)/ton of product.

a) These are for primary smelting processes.
b) A small amount of this tonnage is converted to sulphuric before discharge to acid mist the atmosphere.
c) Assumes 90% recovery of SO_2.

Emission rates from a medium sized power plant boiler are given in Table 7.

Table 7: Typical emission rates from medium sized power plants using coal, fuel oil or gas.

Pollutant	Emission rate	Coal	Oil	Gas
SO_2	mg S/MJ	~400	240	<1
NO_X	mg NO_2 /MJ	250	170	60
Particles	mg/MJ	10*)	5	<1
As	µg/MJ	1.5	0.4	-
Cd	µg/MJ	0.1	0.2	<0.04
Hg	µg/MJ	1.0	0.06	<0.004
V	µg/MJ	7	260	<0.0003
CO_2	g/MJ	110	85	57

*) 1 kg coal ~30 MJ (1.6% S in coal).

Typical emission factors for particulate emissions from different sources are given in Table 8.

Table 8: Typical emission factors for particulate emissions for selected sources.

Emission source	Emission factor
Natural gas combustion	
Power plants	15 *lb*/million ft^3 of gas burned
Industrial boilers	18 *lb*/million ft^3 of gas burned
Domestic and commercial furnaces	19 *lb*/million ft^3 of gas burned
Distillate oil combustion	
Industrial and commercial furnaces	15 *lb*/thousand gallons of oil burned
Domestic furnaces	8 *lb*/thousand gallons of oil burned
Residual oil combustion	
Power plants	10 *lb*/thousand gallons of oil burned
Industrial and commercial furnaces	23 *lb*/thousand gallons of oil burned
Coal combustion	
Cyclone furnaces	2X (ash percent) *lb*/ton of coal burned
Other pulverized coal-fired furnaces	13-17X (ash percent) *lb*/ton of coal burned
Spreader stokers	13X (ash percent) *lb*/ton of coal burned
Other stokers	2-5X (ash percent) *lb*/ton of coal burned
Incineration	
Municipal incinerator (multiple chamber)	17 *lb*/ton of refuse burned
Commercial incinerator (multiple chamber)	3 *lb*/ton of refuse burned
Commercial incinerator (single chamber)	10 *lb*/ton of refuse burned
Flue-fed incinerator	28 *lb*/ton of refuse burned
Domestic incinerator (gas fired)	15 *lb*/ton of refuse burned
Open burning of municipal refuse	16 *lb*/ton of refuse burned
Motor vehicles	
Gasoline-powered engines	12 *lb*/thousand gallons of gasoline burned
Diesel-powered engines	110 *lb*/thousand gallons of diesel fuel burned
Grey iron cupola furnaces	17.4 *lb*/ton of metal charged
Cement manufacturing	38 *lb*/barrel of cement produced
Kraft pulp mills	
Smelt tank	20 *lb*/ton of dried pulp produced
Lime kiln	94 *lb*/ton of dried pulp produced
Recovery furnaces[a)]	150 *lb*/ton of dried pulp produced
Sulphuric acid manufacturing	0.3-7.5 *lb* acid mist/ton of acid produced
Steel manufacturing	
Open-heart furnaces	1.5-20 *lb*/ton of steel produced
Electric-arc furnaces	15 *lb*/ton of metal charged
Aircraft, 4-engine jet	7.4 *lb*/flight
Food and agricultural	
Coffee roasting, direct fired	7.6 *lb*/ton of green coffee beans
Cotton ginning and incinerator of trash	11.7 *lb*/bale of cotton
Feed and grain mills	6 *lb*/ton of product
Secondary metal industry	
Aluminum smelting, chlorination-lancing	1000 *lb*/ton of chlorine
Brass and bronze smelting, reverberatory furnace	26.3 *lb*/ton of metal charged

[a)] With primary stack gas scrubber.

Sources: *Air Quality Criteria for Particulate Matter*, AP-49, National Air Pollution Control Administration, January 1969; and *Control Techniques for Particulate Air Pollutants*, AP-51, National Air Pollution Control Administration, January 1969.

6.1.3 Emissions from road traffic

6.1.3.1 Methodology

The emissions of CO and NO_x from traffic is calculated by multiplying the traffic intensity (cars/hour) with the length of the road (km) and an "emission factor" (g/(km*car)). For CO_2, the emission factor (grams of emission per unit fuel consumption) is multiplied with the fuel consumption (kg/km).

The emission for a given road is a function of:

- speed
- road gradient
- year of calculation (this determines the technology level of the vehicle)
- number of cars in each vehicle class.

The emissions increase with the age of the car. There are also increased emissions from cars in cold start mode. Both of these factors can be accounted for in a model.

The total emission from the road network (tonnes/year) is estimated from the mean daily traffic parameters. The peak emission calculations utilizes rush-hour parameters.

The calculation of emissions/generation of PM_{10} (road dust) is usually based on a different method than for the other components. The reason for this is that PM_{10} refers to a 24 hour average, whereas CO and NO_2 are one hour averages.
As an example on the complexity of emission models the emission description in the NILU model ROADAIR is included.

6.1.3.2 Vehicle classes

The vehicle fleet consists of different classes of vehicles (Table 9). The classification is based on the relation between vehicle type and the respective exhaust demands. The classification used in Norway is called The National Emission Model (NU) (SFT, 1993), except that in this model it was decided not to account for gasoline trucks, vans and buses. In 1991 those classes accounted for approximately 2% of the total traffic work in Norway (SFT, 1993). This implies that the two concentration calculation results will not differ significantly. Light and heavy duty diesel trucks are for simplicity grouped together in one class. This emission model is a part of a road traffic dispersion model called ROADAIR and is also used at NILU in the model system KILDER that calculates long time concentrations inn cities with complex emission fields.

Table 9: Classification of vehicle classes in ROADAIR 3.1.

Class	Type	Fuel	Max. load	Weight
BL1	Light cars	Gasoline	< 760 kg	< 3.5 tonnes
DL1	Light cars	Diesel	< 760 kg	< 3.5 tonnes
DL2	Light vans	Diesel	> 760 kg	< 2.7 tonnes
DL3	Heavy vans	Diesel	> 760 kg	2.7-3.5 tonnes
DHLL	Trucks	Diesel	> 760 kg	3.5-10 tonnes
DHLM	Trucks	Diesel	> 760 kg	10-20 tonnes
DHLL	Trucks	Diesel	> 760 kg	> 20 tonnes
DHB	Buses	Diesel	> 760 kg	> 3.5 tonnes

6.1.4 The conception "emission factor" for road traffic

The emission factor represents the average emission for a certain distance given in g/km or g/kWh. ROADAIR 3.11 uses emission factors as a function of speed (interpolation between every 10 km/h). Both the one-hour average (during rush hour) and the 24-hour average speeds are input data to the model. The emission factor for i.e. 60 km/h speed does not represent the emission at constant speed fluctuation, but the emission along a road with a speed limit of 60 km/h. The speed will fluctuate around 60 km/h, including both acceleration and retardation. There are expected to be more accelerations and retardations for lower speeds, (queue-driving). It is assumed a lowest average one hour speed of 10 km/h.

The following have been included when estimating emission factors for a vehicle class:

- The vehicles within a vehicle class for a given year represent different technology levels. The emissions from a vehicle depend on the emission demands that were valid when the vehicle was first registered.

- The emissions from a vehicle increases with the age of the vehicle. The ageing is a function of accumulated driving length.

- The emissions is influenced of cold start. The effect of cold start is different for different technology levels. It is assumed that a certain fraction of the vehicles are in cold start mode at all times. This fraction is a function of vehicle type, road class, area type and time of day (see chapter 3.2 in the ROADAIR 3.11,1996).

- Driving uphill at constant speed is equal to acceleration (concerning emissions), and downhill is equal to retardation. Emissions from heavy duty vehicles are approximately zero when they break, or when they drive downhill when the gas pedal is not in use.

6.2 The emission inventory data base

A modern environmental monitoring and information system have to handle a lot of measured, collected and generated data. To keep track of all these data and to make them accessible in an easy way it is convenient to organize the data in a database system. The database system may consist of several databases which have to serve as main storage platforms for:

- On-line emission measurements,
- emission and discharge data including emission modelling procedures,
- historical data (i.e. trends) and background information (area use, population distributions etc.)
- procedures for consequence analysis, guideline values, use of guidelines, regulations etc.

The data bases contain information to enable an evaluation of the actual emissions and it include data for establishing trend analysis, warnings and to undertake countermeasures in case of episodic high emissions.

The emission data base is an interactive platform which contains input data for emission estimates. It contains information about sources, emission factors, consumption data, information on location (gridded co-ordinates), stack heights, stack parameters, fuels etc.(i.e. EMEP). The emission data base can be operated directly by the user who can use emission models to present the emission data for different sources. Any changes and/or additions to the emission data base will result in updated emission estimates with links to the dispersion models and resulting database for graphical presentation.

All emission data collected on-line will after quality assurance and quality controls be part of larger emission data base. From this base it will be possible to present the data graphically, and to extract data for public information purposes etc.

The emission data can also contain information on regulations, requirements, emission regulations. Information about regulations and plans given by local authorities or by governmental institutions should be included in this data base, as well as support actions and emergency procedures.

The total associated data base system can also serve as a link to a meta information system which include information on external environmental data, these functions might also include:

- Navigation facilities to access the needed information
- support for standardization activities
- world wide web/ internet functions and other connections

6.3 Dispersion models

Numerical and statistical models are being used in air pollution studies of various content and complexity. The models can roughly be divided into two main types:

1. Source oriented models
2. Receptor models

The source oriented models combine information about sources (emission inventories), meteorology and topography to estimate concentration distributions.

Receptor models use measured concentrations of various air pollutants over long time periods and can by statistical analyses identify source impact and the different source`s contribution to the concentration measured at specific points. The difference in the two types of models are illustrated in
Figure 41.

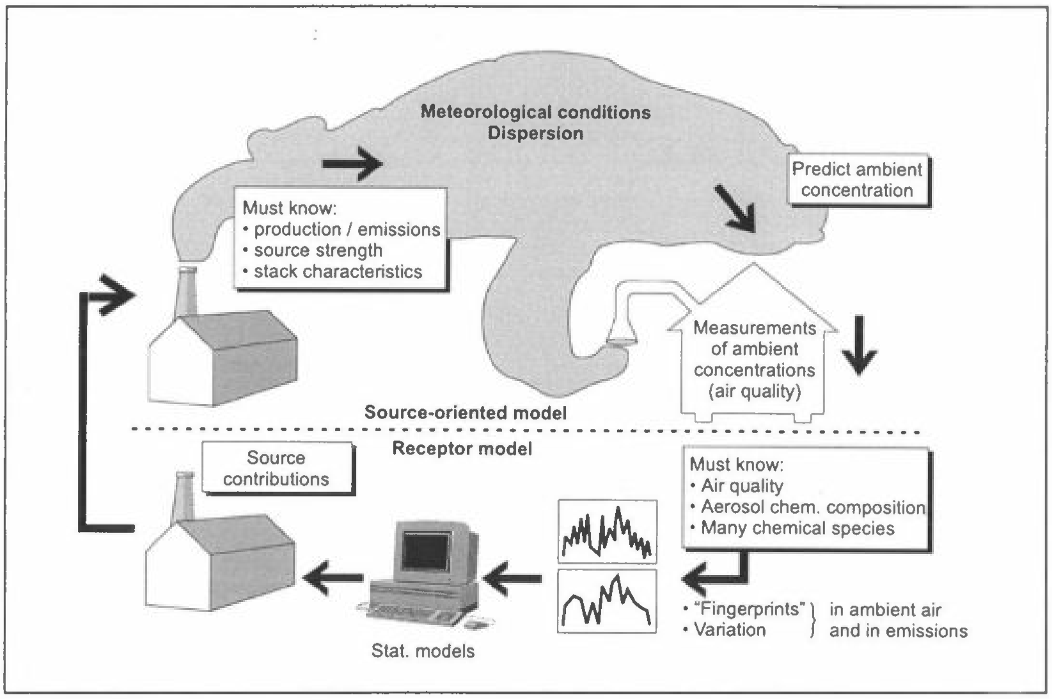


Figure 41: Source oriented and receptor models work from different input data.

The receptor model has been applied when large data sets of good air quality data have been available to explain the contributions from different source types. The most commonly used type of models have, however, been the source oriented models.

The source models estimate the atmospheres ability to transport and disperse air pollution emissions and have been used both for gases (inert and reactive gases) and for particles and aerosols. These models are important when evaluating the impact of future emissions and to analyse what causes the impact on air quality in general. These type of models have recently been linked to air quality monitoring and surveillance programmes, and they are frequently used for impact assessment, abatement strategy planning and for air quality planning purposes in general.

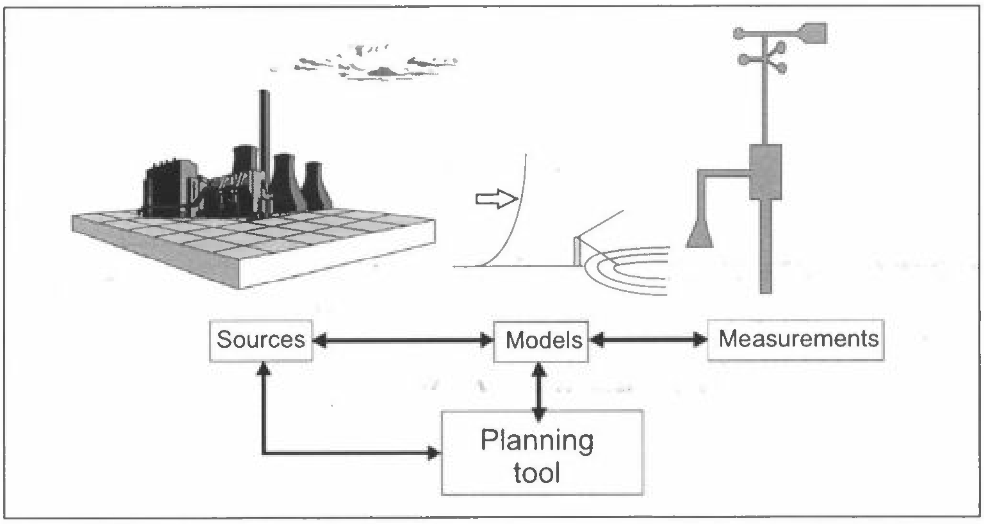


Figure 42: Source oriented models establish the connection between sources and air quality.

A large number of source oriented models are available on all scales (space and time). The models focus on different parameters for different scales. On the smallest scale, atmospheric turbulence, buoyancy effects, surface roughness and fluctuations of wind speed plays an important role. On the larger scale, the large scale weather patterns, chemical transformations and deposition are important.

Early air quality model development was based on local scale problems. Since the 1970s also long range air pollution transport models have been developed. Advanced mesoscale dispersion models for distances 10-300 km have not been developed especially for operational purposes. Most of the models were developed purely for scientific reasons. Investigations of mesoscale circulations (i.e. land/sea breeze) for input to mesoscale dispersion models have been limited.

The different types of models treat the various elements of modelling differently, such as

- source characteristics,
- transport of pollutants,
- diffusion,
- plume buoyancy,
- deposition,
- chemical reactions etc.

The different models may roughly be divided into the following categories:

- Gaussian plume models
- Numerical models
- Trajectory models (puff, segment, etc.)
- Box models
- Statistical models

The models may also be characterized according to the investigated pollutant

- inert passive gas,
- gases influenced by physical processes (deposition, fall-out)
- heavy gas,
- gases subjected to chemical reactions in the atmosphere.

In the following local to mesoscale type dispersion models will be described. These models are often applied together with monitoring and surveillance programmes and used in air quality planning. All the models are source oriented models.

6.3.1 The Gaussian plume model

Gaussian type models are based on Gaussian (normal) probability distribution of the concentration (particle density) in both the vertical and horizontal direction perpendicular to the plume centreline. These models represent simple analytical solutions to the continuity equation which require homogenous and steady state conditions. The model concept is shown in
Figure 43.

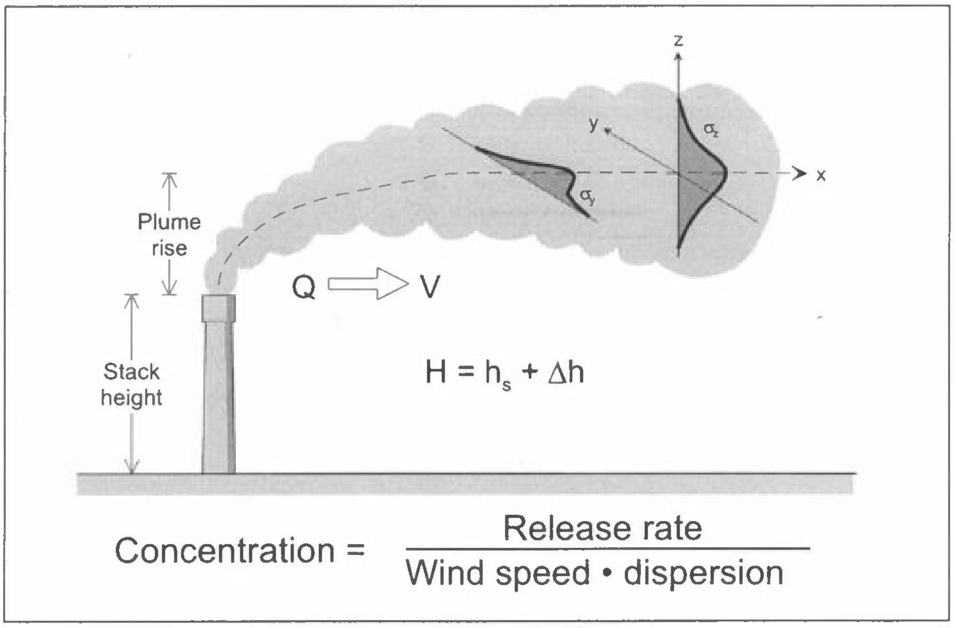


Figure 43: The concept of the Gaussian plume model.

Gaussian type dispersion models are the most commonly applied models in practical use to day. The equation for calculating the concentration (C) at ground level, assuming total reflection of the plume at the surface, can be written:

$$C = Q\left[\exp\left(-H^2 / 2\sigma_z^2\right)\cdot\left(-y^2 / 2\sigma_y^2\right)\right] / \left(\pi\sigma_y\sigma_z \cdot u\right)$$

where Q = release rate (μg/s)
H = effective plume height $\left(h_s + dh\right)$
σ_y, σ_z = dispersion parameters (m)

The co-ordinate y refers to horizontal direction perdendicular to the plume axis, and z is the height above the ground. The ground is assumed to be flat and uniform.

The parameters σ_y and σ_z are the standard deviations of the concentration distribution in y and z directions, respectively. The parameters are usually referred to as the diffusion parameters. The values σ_y and σ_z are functions of the turbulent state of the atmosphere, which again is a function of the mechanical induced turbulence (wind shear, wind profile) and the convective turbulence (temperature profile).

Stability classes

In the absence of measurements to estimate σ_y and σ_z of turbulence the turbulent state and the stability of the boundary layer is usually divided into classes, preferably by a simple scheme based on inexpensive measurement data. The most widely used scheme was developed by Pasquill (1974) and was modified slightly by Turner in 1981:

A = extremely unstable (low wind, summer, day time)
B = moderately unstable
C = slightly unstable
D = neutral (overcast high winds)
E = slightly stable
F = stable (inversions, cold winter nights)

A simplified classification scheme has been introduced based upon temperature gradient measurements along a meteorological tower. The following classification can be used as input to long term average concentration estimates (CDM models):

Class	Temp. gradient dT (deg/100 m)	Correspond to: Pasquill	Klug	Brookhaven
Unstable	dT <1	A + B + C	IV + V	$B_1 + B_2$
Neutral	$-1 \leq$ dT <0	D	$III_1 + III_2$	C
Slightly stable	$0 \leq$ dT <0	E	II	-
Stable	dT $\geq$1	F	I	D

Diffusion parameters

The diffusion parameter σ_y and σ_z can be found from empirical curves as a function of the distance from the source (Figure 44).

Such curves have been established by several authors (Pasquill, 1961; Gifford, 1961; Irwin, 1979) based upon various types of dispersion experiments. Today estimates are usually performed by computers or calculators and most people would rather have a formula than a graph.

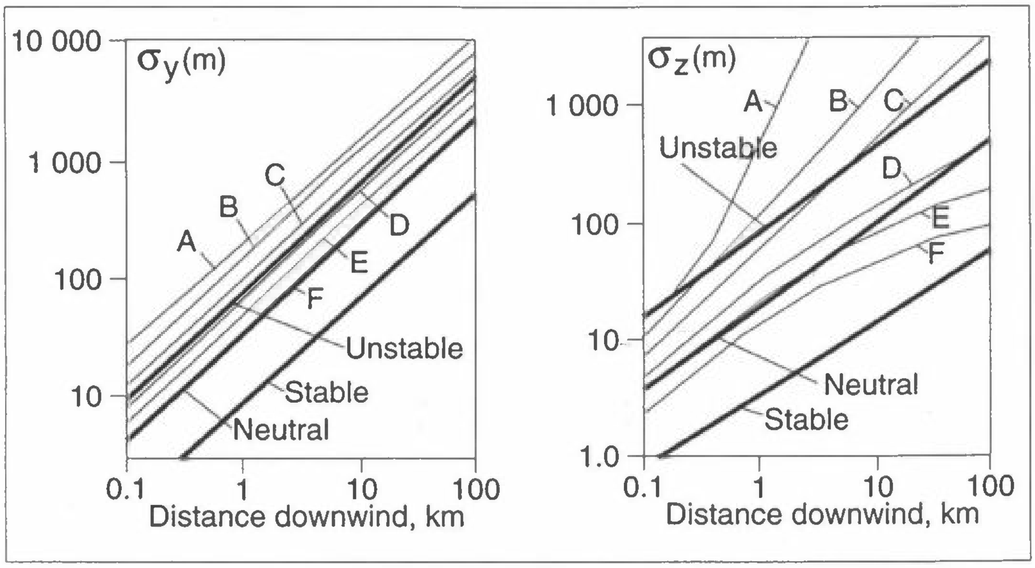


Figure 44: Dispersion coefficient σ_y and σ_z as functions of down wind distance from the source (empirical values based upon dispersion experiments).

The most widely used formula has been established as the power law of distance:

$$\sigma_y = ax^P \text{ and } \sigma_z = bx^q$$

Numerical values for a, p, b and q have been set up for different surface conditions, for low and high stacks, and for area sources as shown in Table 10.

Table 10: Parameter values for diffusion coefficients $\sigma_y = ax^p, \sigma_z = bx^q$.

Source and surface specifications	Coefficients	Unst.	Neutr.	Sl. stable	Stable
Surface emission Low stacks Smooth surface	a	0.31	0.22	0.24	0.27
	p	0.89	0.80	0.69	0.59
	b	0.07	0.10	0.22	0.26
	q	1.02	0.80	0.61	0.50
Surface and low sources (area sources Rough surface, urban	a	1.7	0.91	1.02	-
	p	0.72	0.73	0.65	-
	b	0.08	0.91	1.93	-
	q	1.2	0.70	0.47	-
High stacks Smooth to medium rough surface	a	0.36	0.32	0.31	0.31
	p	0.86	0.78	0.74	0.71
	b	0.33	0.22	0.16	0.06
	q	0.86	0.78	0.74	0.71
High stacks Rough surface	a	0.23	0.22	1.69	5.38
	p	0.97	0.91	0.62	0.57
	b	0.16	0.40	0.16	0.40
	q	1.02	0.76	0.81	0.62

The effective plume height, H

The effective plume height (H) is defined as the total plume height above the ground, which is the sum of the stack height (h_s) and plume rise (dh).

Plume rise estimates are very important when determining maximum ground level concentrations due to emissions from stacks. The maximum ground level concentration is roughly proportional to the inverse square of the effective stack height. The plume rise can sometimes increase the plume height compared to the stack height by a factor 2-10.

The plume rise is a combination of buoyancy flux

$$F = g \cdot V (T_g - T_a)/T_g$$

and momentum flux

$$M = w \cdot V$$

where: V = volume flux = $w \cdot r^2$
T_g = plume temperature
T_a = ambient air temperature
w = vertical plume speed
r = plume radius

Assuming that F_0 is the buoyancy flux at the stack exit, Briggs (1981) recommended for buoyancy dominated plumes (power plants, etc...) that

$$dh = 1.6 \cdot F_0^{1/3}\, x^{2/3} u^{-1}$$

This famous "2/3 law" has shown to agree well with observations.

During stable atmospheric conditions the vertical motion of the plume is supressed. The plume rise is then inversely proportional to the stability

$$s = g\left(\delta T_a / \delta_z + 0.01\right) / T_a$$

The plume rise for stable atmospheric conditions can be written:

$$dh = 2.6\left(F_0 / (u \cdot s)\right)^{1/3}$$

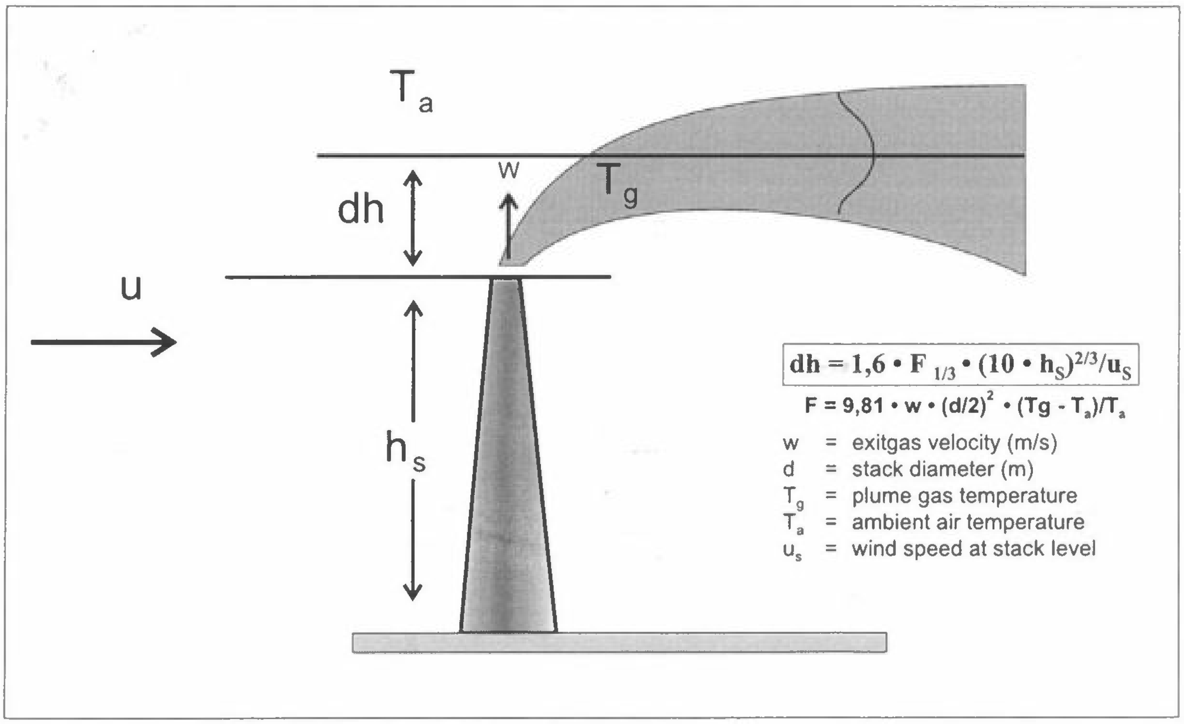


Figure 45: Plume rise (bent over plume).

Wind speed

The horizontal wind speed u in the Gaussian plume model can not be zero. Anemometers measuring wind near the surface may register u = 0 (calm conditions). However, in the planetary boundary layer the horizontal wind speed is very seldom calm. For modelling purposes the wind speed u is usually set to 0.5 m/s for "calm conditions".

For estimating plume rise the effective wind speed at the stack height should be used. In Gaussian plume models a simple power law formula has been applied for this purpose:

$$u = u_{10}\,(z / 10)^m$$

where u_{10} is the observed wind at 10 m is given as a function of stability and surface conditions (Table 11).

Table 11: The values of m in the power law wind profile.

Surface	Unstable	Neutral	Light stable	Stable
Urban	0.2	0.25	0.4	0.6
Rural	0.1	0.15	0.35	0.5
"Kilder"	0.2	0.28	0.36	0.42

6.3.2 Traffic and car exhaust models

Several models have been developed to calculate air pollution from road traffic. These models are handling many sources that vary strongly with time of day. They therefore often use statistical models for emission calculations and combine these with dispersion models of different types. The dispersion model is different for street canyons and open roads (highways).

Highways

Several line source dispersion models suitable for calculating air pollution concentrations from exhaust emissions along roads have been developed. Some of the well known models for highways are HIWAY-2, CALINE 1-4 and GM-line. (Petersen, 1980). NILU has chosen to use the HIWAY-2 model. The HIWAY-2 model, and a modified version of it, in which the initial dispersion due to car induced turbulence is not a function of car speed, is utilized for roads in areas with scattered buildings and vegetation.

Street canyons

For street canyons, the basic model used is the APRAC model (Dabberdt, W.F. et al., 1973), a semi empirical model developed at Stanford University. In a Nordic co-operative study, this model was further developed based on an extensive Swedish-Norwegian measurement data base. It has been designated " Nordic Curbside Pollution Model", and is used extensively to calculate concentrations of CO and NO_2 in street canyons.

In a revised version of the Nordic model, a new dispersion module for street canyons Operational Street Pollution Model (OSPM) has been developed by the Danish National Air Quality Laboratory. (Hertel and Berkowicz, 1989a, b). The OSPM model describes more accurately the influence of wind direction and height of the buildings along the street than the APRAC model does.

Integrated road and street models

Based on the APRAC/OSPM and HIWAY-2 models, NILU has developed a model which calculates emissions and maximum concentrations for chosen air pollution parameters along road networks (ROADAIR). (Bekkestad et al., 1996)

The ROADAIR model calculates:

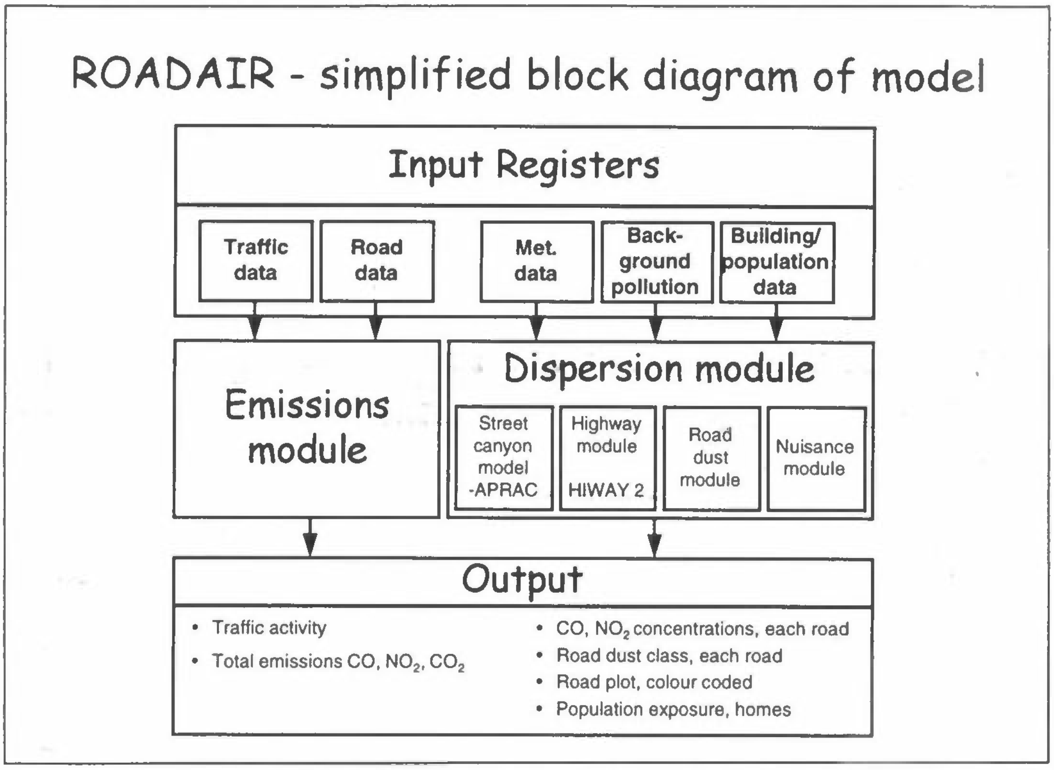
- Emissions of CO, NO_x and CO_2 from the traffic on each road link,
- concentrations of CO, NO_2 and PM_{10} at chosen distance from the road curb for each road link,
- road dust deposition (g/m^2 month) along each road link,
- population exposure to CO, NO_2 and PM_{10} ,
- nuisance from air pollution experienced by persons in their residence.

Figure 46 shows a block diagram of the model, and indicate the required input data necessary to estimate the specified output.

Figure 47 gives an overview of the necessary input data.

Figure 48 shows one example from estimates using traffic models. The relative reduction of the maximum 1 hour concentration for different distances from the road, as calculated by the HIWAY module in ROADAIR compared to measured concentration reduction with distance. The examples show long-term concentrations of black smoke (particles) and deposition of road dust (pr. m^2).

The total road network modelling system can also estimate emissions and concentrations along the whole road and street network as shown in Figure 49.



ROADAIR - simplified block diagram of model

Input Registers

- Traffic data
- Road data
- Met. data
- Back-ground pollution
- Building/ population data

Emissions module

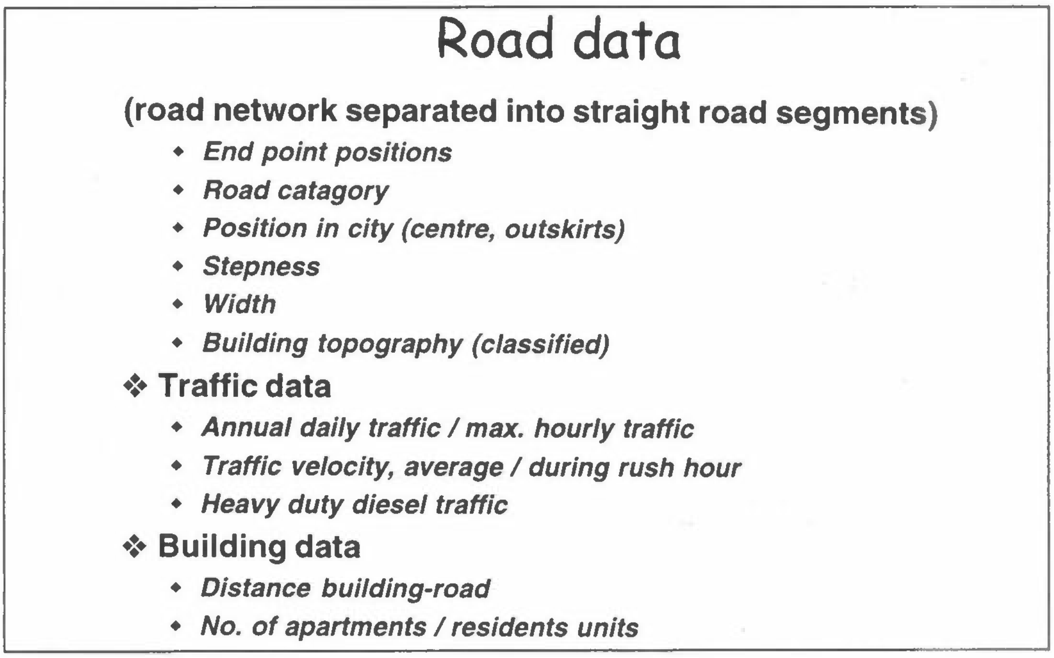
Dispersion module

- Street canyon model -APRAC
- Highway module HIWAY 2
- Road dust module
- Nuisance module

Output

- Traffic activity
- Total emissions CO, NO_2, CO_2
- CO, NO_2 concentrations, each road
- Road dust class, each road
- Road plot, colour coded
- Population exposure, homes

Figure 46: ROADAIR. Simplified block diagram of model



Road data

(road network separated into straight road segments)

- *End point positions*
- *Road catagory*
- *Position in city (centre, outskirts)*
- *Stepness*
- *Width*
- *Building topography (classified)*

❖ Traffic data

- *Annual daily traffic / max. hourly traffic*
- *Traffic velocity, average / during rush hour*
- *Heavy duty diesel traffic*

❖ Building data

- *Distance building-road*
- *No. of apartments / residents units*

Figure 47: ROADAIR. Overview of necessary input data

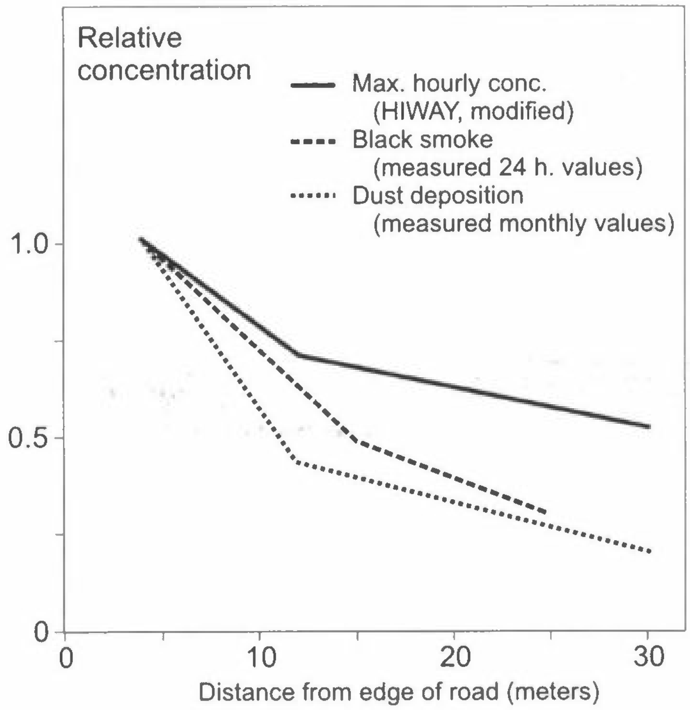


Figure 48: Examples of reduction in air pollution concentrations with distance from a highway, estimated by one module in ROADAIR and compared with measurement data..

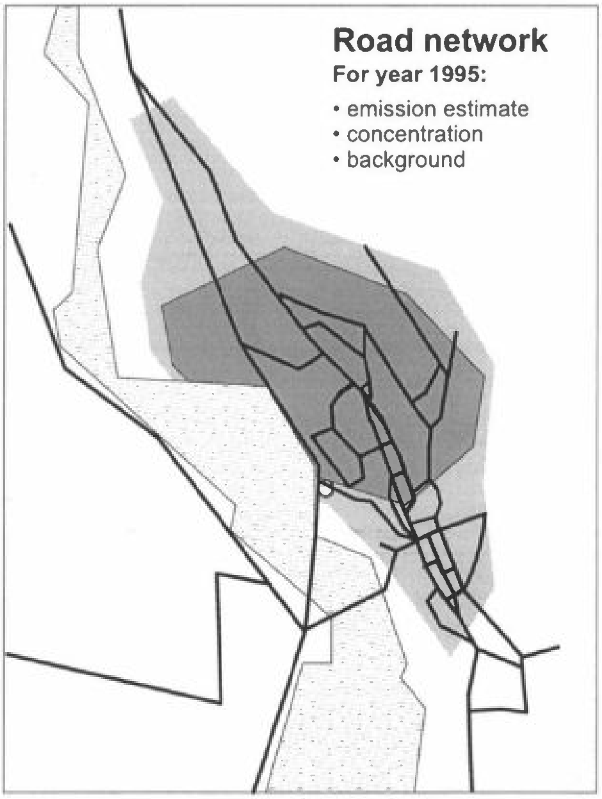


Figure 49: ROADAIR. Example of plot of road system with each road classified according to the calculated maximum 1- hourly CO concentrations. The example shows NO_2 concentrations along the road system in the city of Lillehammer.

6.3.3 Puff trajectory models

Puff trajectory models are designed to simulate dispersion from semi-instantaneous or continuous point sources over a spatially and temporally variable wind field. The trajectory models can normally treat multiple sources.

The plume is represented by airparcels (puffs, segments). Each air parcel represents a segment of the plume. The dispersion of each puff can be represented in several ways. Commonly simple Gaussian concentration distributions are assumed along the horizontal and vertical axis. Concentrations of pollutants in specific receptor points are estimated by the sum of a complex combination of puffs from many sources. The puff trajectory models are often applied for situations with complex meteorology (time and space dependent meteorology, i.e. land/sea breeze, mountain/valley wind etc.). It is necessary to know the wind field of the area in question.

The most commonly applied puff trajectory models represent the plume by air parcels emitted from the stack at given time intervals. The total number of air parcels jointly represent the plume. The puffs are transported within the wind field and the dilution is estimated using local diffusion factors. The dispersion of the puffs can be calculated using Gaussian concentration distributions in the puff, but other descriptions are also possible. Different Gaussian dispersion algorithms can be used (see ch. 6.2). The Gaussian dispersion algorithms are usually functions of time or distance. The time dependency is most useful for puff trajectory models.

Some of the features that can be included in a puff trajectory model are

- meteorology that vary in time and space,
- multiple point sources,
- time dependent emissions,
- dry and wet deposition estimates,
- variable output averaging times,
- concentrations given in specific receptor points or in a grid.

Puff trajectory models are flexible and are valid for a number of dispersion problems. They are however less accurate than the Gaussian dispersion models for calculation of long time averages because it is difficult to get reliable meteorological data, emissions and dispersion parameters on an hourly basis to correctly describe a half year average. Calculations with puff trajectory models for half a year also implies a lot of extra work, which is not necessary when the Gaussian dispersion models for long term averages produce reliable results.

6.3.4 Numerical models

Numerical models are based on numerical solution of the continuity equations. Several numerical schemes for solving the equations, varying in complexity, accuracy and computing speed, have been applied. The solution methodology will depend upon the scale (in space and time) of the problem. The numerical transport/diffusion models overcome the difficulties of the Gaussian plume models to simulate complicated situations like non-stationary and inhomogeneous conditions, as well as with calm situations and weak wind.

These complicated situations require a detailed knowledge of the three-dimensional structure and its temporal variation for the relevant meteorological variables and, sometimes, of initial condition for the numerical solution of the elementary equation. Thus a rather large amount of input data, additional restrictive assumptions, or a comprehensive closed set of differential equations for all relevant variables is necessary for an adequate treatment of the problem.

6.3.5 Box models

Box-models are based on the idea that the temporal variation of air pollution concentrations in a clearly defined area can be described considering input and output (sources and sinks) within a schematic "budget-box".

Box models can be divided into the following:

- Simple box-models: Considers the whole urban area as a single box, with spatially undifferentiated predictions of short- or long-range trends of urban air pollution concentrations.
- Multiple box-models: The urban area is divided into a grid of horizontal boxes. Multiple box-models permit spatial differentiation it and estimates the fluxes in and out of the boxes.

6.3.6 Statistical models

Statistical models associate the probability distribution of pollutant concentration fields to a set of meteorological parameters that characterizes the actual meteorological situation. These models commonly make use of multiple regression analysis of measured data. The results are described by means of empirical relations, tabulation schemes, empirical orthogonal functions, or variational methods. Statistical models in this sense can usually not be applied in planning or for environmental impact analyses, such as predicting the impact from planned changes in the emission fields.

6.4 Model applications

Air quality dispersion models have been and are being used for several purposes. Some of the most important areas in which models are of greatest importance are in

1. siting studies,
2. for environmental planning purposes,
3. environmental impact assessment reporting.

A more detailed list of possible uses of dispersion models may contain

- calculation of stack heights for single sources,
- impact assessment from large point sources,
- estimate results of emission controls,
- accidental release impact,
- deposition of aerosols and gases to vegetation,
- odour evaluation,
- estimate photochemical oxidant potential,
- impact of distant sources,
- land-use planning,
- traffic planning,
- planning of measurement programmes,
- analyses of measurement data,
- forecasting of episodes,
- environmental impact assessment,
- implementation plans.

Operational dispersion models contain the type of input data that has been described earlier in this chapter:

- Emission data,
- meteorology (wind, turbulence, temperature),
- chemical reaction mechanisms,
- deposition mechanisms.

The input to these models may come from a monitoring programme or be taken from historical data records or pre-estimated variables.
Figure 50 indicate the procedures of an operational model.

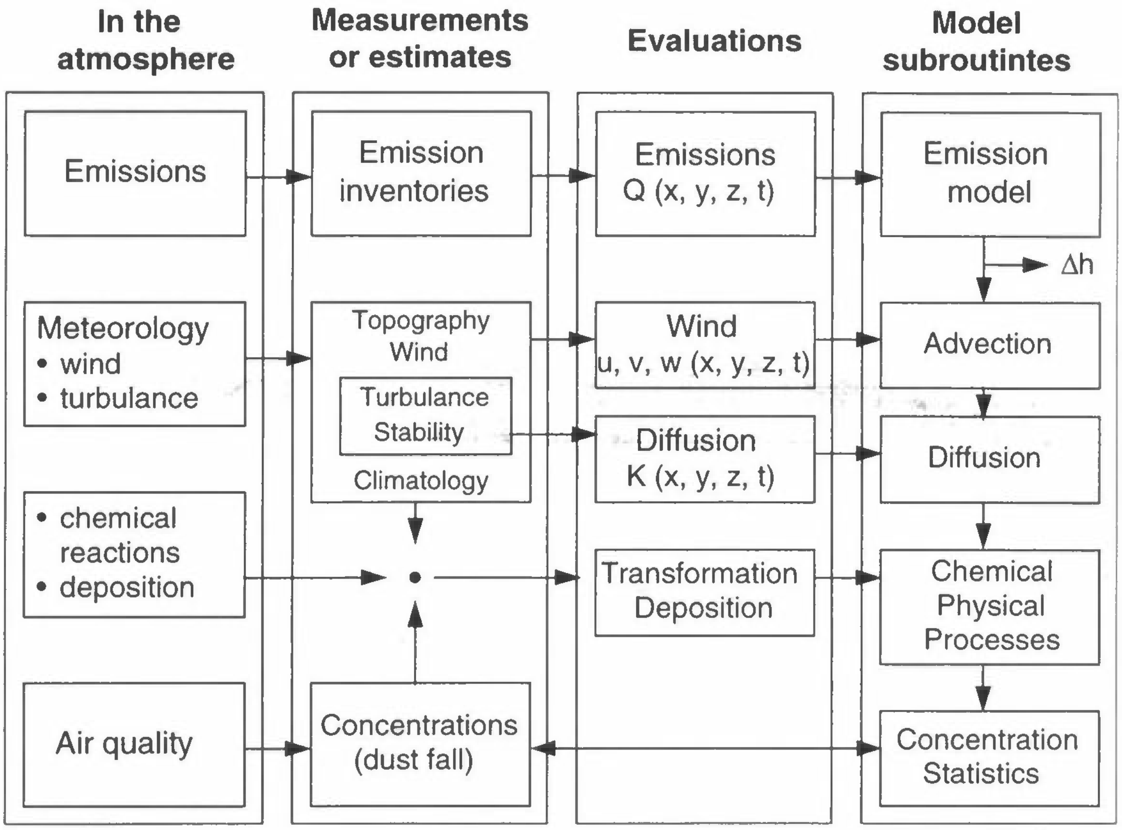


Figure 50: The procedure of an operational dispersion model used in practical applications.

A dispersion model is often more useful than a measurement programme. At least together with measured air quality data the model is superior compared to the single point measurement data only.

The type of model to be utilized for a specific application will be dependent upon several factors such as:

- Accuracy
- Available computer capacity
- Economic resources
- Source types (chemical compounds)
- Point source/area source
- Continuos or puff-release
- Terrain (type, complexity, surface)
- Scale (time and space)
- Averaging time for estimated concentrations

A model produces a complete picture of the concentration distribution for an area. A source oriented model can calculate the contribution, and evaluate the importance, of each source to the total picture.

Models can also be used to evaluate the representativity of measured data. A screening of the maximum ground level impact from stacks and low sources can be obtained from a simple single source Gaussian type dispersion model (Figure 51.)

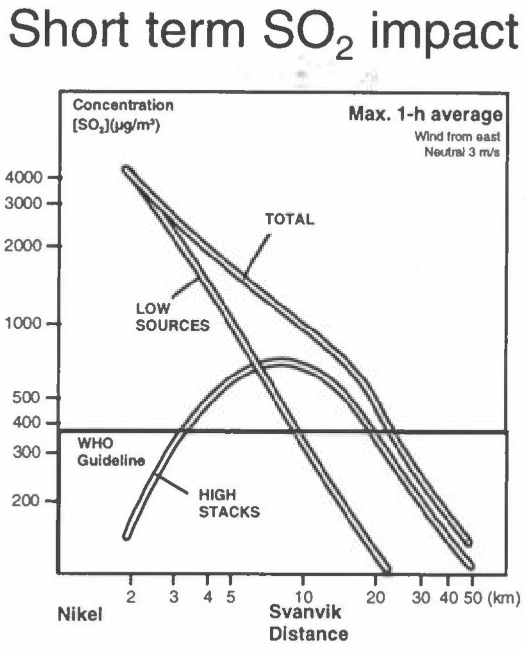


Figure 51: Model estimated SO_2 concentrations as a function of distance from a Nickel smelter. About 80 % of emissions are released from 150 m tall stacks Less than 20 % of the emissions are from low sources in the building complex. Emission from the low sources are still shown to dominate the ground level concentrations up to a distance of approximately 10 km from the source..

When models are applied together with on line measurement of meteorology and air quality as part of the modern air quality monitoring and surveillance programme it is also possible to establish a system for automatic air pollution alarm.

Figure 52 present the content of alarm systems that have been established in highly industrialized areas.

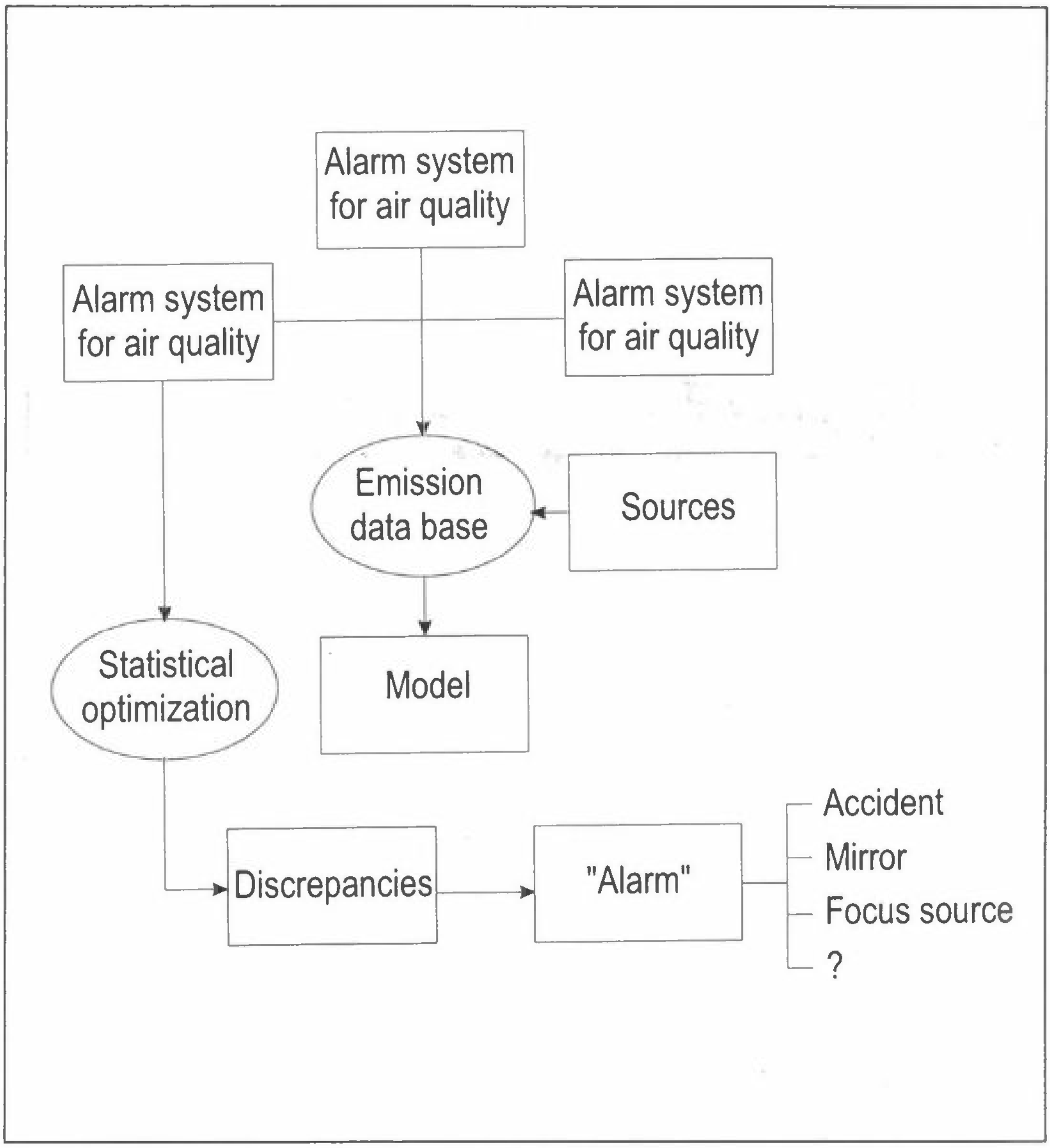


Figure 52: An on-line air pollution alarm system based upon a modern monitoring and surveillance system.

From on-line air-quality data and meteorological data the numerical computer models can estimate expected air pollution concentration distributions for every selected time step (most often hourly or each 5 minute). These concentration distributions are based upon the emission data measured or estimated for the sources of the area. Discrepancies from single point measurements or path integrated measurements will occur on the PC screen as an "alarm", and will tell the user that there are high concentrations that are being measured and that should not be expected (
Figure 52).

The air quality system will give alarm when the measured concentrations are above certain limits. The model system can determine what causes the concentrations, such as unfavourable meteorological conditions or accidental releases. The authorities can further take action and find out or question the possible source areas pointed out by the modelling system. Such a system has been developed for two separate urban areas in an industrial region of southern Norway.

Graphical presentation of air pollution data/concentrations of air pollution for an area can be used to present information to the public. In Oslo, Norway, the on-line continuous air pollution monitoring system AirQUIS has been used to issue daily information and forecast of the air pollution levels (air quality) through local radio stations. This information has been classified according to low, medium and high air pollution levels. The levels of selected indicators can further be related to national Air Quality guideline values or to international (WHO) regulations or guidelines.

Forecasting of high air pollution episodes will have to rely upon a forecast of meteorological conditions. A parameterization of the meteorological conditions used as input to the model system can give valuable information to air pollution episode forecasting.

The on-line surveillance and modelling system can also be used to estimate future impact resulting from changes in the emission conditions. It can also, when operative, be used for designing optimal abatement strategies (see chapter 8.4).

7. Data Presentation

7.1 Air pollution statistics

Standardized statistical analysis should be performed to assess air quality trends, changes in emissions or impact from specific types or groups of sources. The severity of the air pollution problem or the air quality should be specified relative to air quality guideline (AQG) values, standards or pre defined levels of classification (e.g. good, moderate, unhealthy, hazardous ......)

The number of hours and days, or percentage of time when the air pollution concentrations have exceeded AQG values should be presented. This will also need minimum requirements of data base completeness. Long term averages (annual or seasonal) should be presented relative to AQG. In the Norwegian surveillance programme the winter average values of SO_2 and NO_2 are presented on maps in percent of the national air quality guideline values.

Before undertaking statistical evaluations the data should be presented and validated based upon a form of time series. These data must be evaluated logically to correct for drift in instruments, and eliminate data that are identified to be include errors. It is also important that the data are checked with other relevant information. A an example of this is shown in Figure 53.

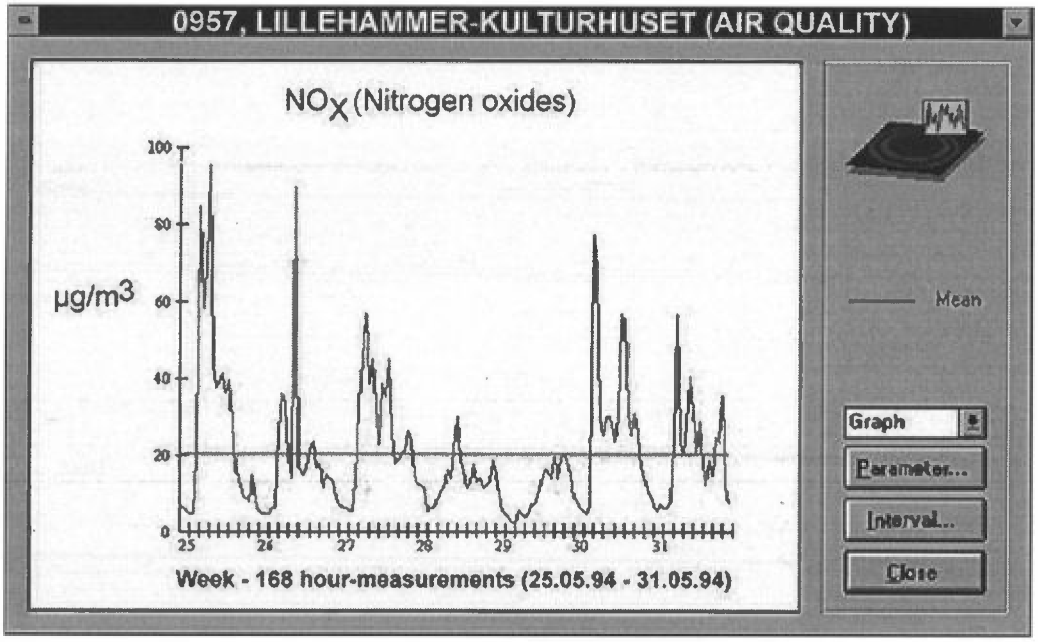


Figure 53: Time plot of NO_x concentrations as shown on the screen from data quality control.

After an analysis of the time plot the approved data can be handled in different ways statistically.

Air quality data are most often presented as

- time series,
- cumulative frequency distributions, where the frequency distribution should be referred to air quality standards,
- average concentration distributions at various monitoring sites as function of wind directions (Breuer diagrams or concentration "roses"),
- Scatter plots which can be used for interrelation between simultaneous air quality measurements, meteorological variables or other relevant data,
- average concentration as function of time of day.

The statistical programmes mentioned above are the most commonly used when evaluating measured data. The following chapters will present some examples on how the results can be presented and used.

In addition to the measured data, statistical analysis of calculated concentrations can give additional information of the air pollution distribution for areas where measurement data are not available. This is usually done with the same type of statistical methods as mentioned above.

Special statistical analysis of comparison between measured and calculated parameters are available. Different interpolation routines are available for handling of measured data in a grid. One such method which is frequently applied is kriging - an interpolation of measured concentrations in a grid. Three kriging procedures are used: simple, ordinary and universal. The presentation of spatial distribution of background air pollution data for Europe have been based on kriging.

Some of these statistical procedures can easily be handled in a normal spread sheet like EXCEL on a personal computer. But some need special programs. At NILU the AirQUIS system has been developed to take care of the data bases and some of the statistics used for presentation of results.

Examples of concentration frequency distribution and the scatter plot are shown in Figure 54.

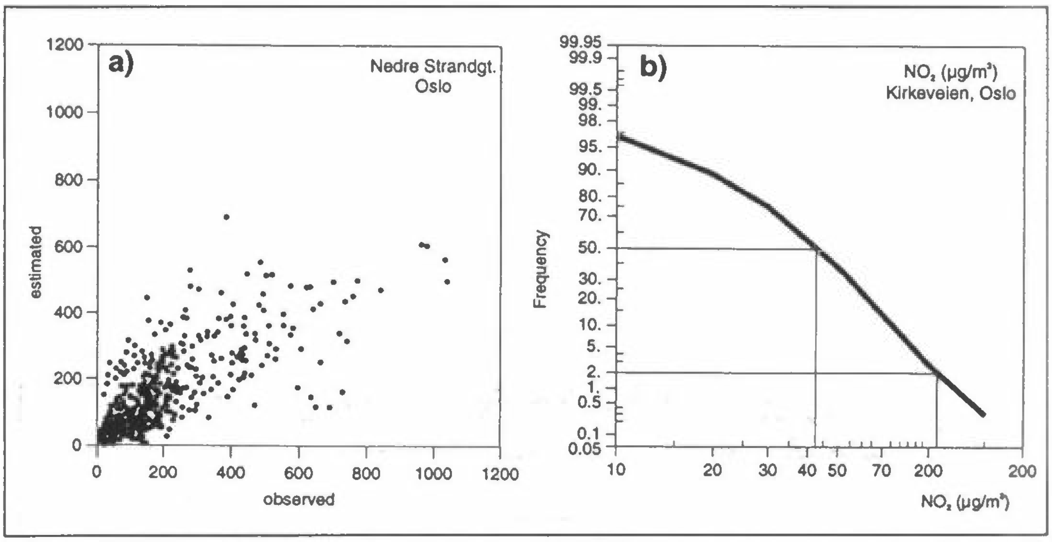


Figure 54: a) Scatter plot of measured vs. observed data.
b) Cumulative frequency distribution of NO_2 concentrations.

The "concentration rose" is handy when investigating the impact of specific sources. This analyses will give the average concentration as a function of wind direction. An example of a "concentration rose" is shown in Figure 55.

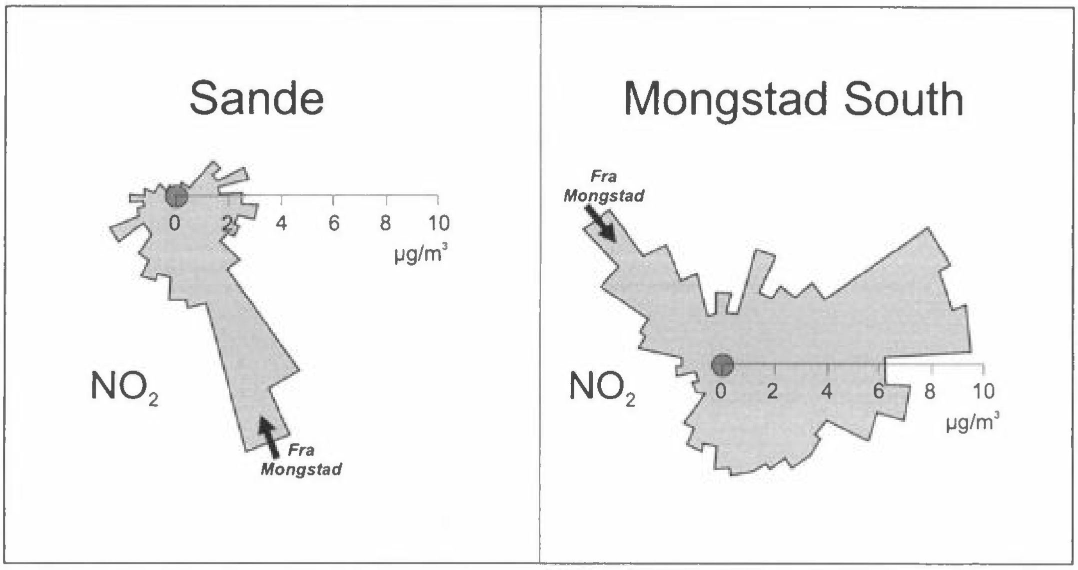


Figure 55: "Concentration rose", (Breuer diagram) established for two measurement sites at an oil refinery.

As an example of average frequency distribution as a function of time of the day, the occurrence (in %) of 4 stability classes are shown in Figure 56. The following chapters will present further examples of data presentations using various statistical programmes.

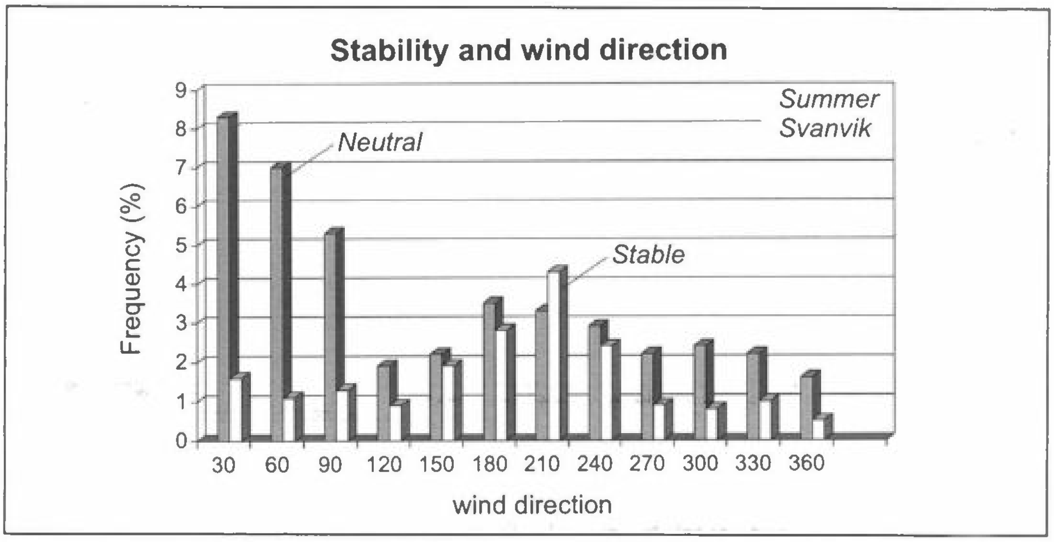


Figure 56: Frequency distribution of stability as a function of wind direction, taken from a joint frequency distribution of wind and stability.

7.2 Emission data

Emission data are usually divided into:

- Point sources(Industrial and large domestic sources)
- Area sources (domestic heating), small scale industries, agriculture, etc.)
- Line sources (road traffic, ships etc.)

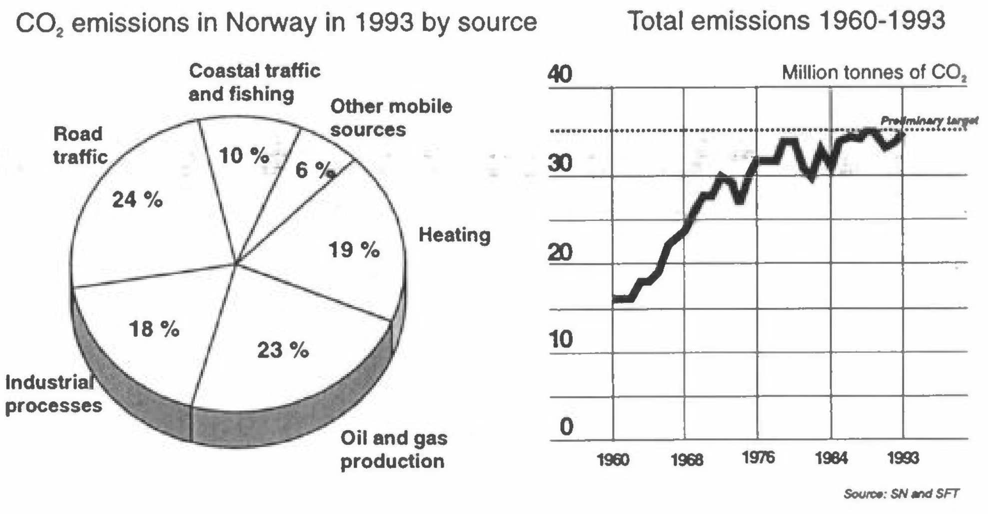
The evaluation of individual emissions or groups of emissions have been performed to establish an overall emission survey, given as annual average emissions. These results are often tabulated and presented as emissions from different source categories.. Table 12 gives an example of such presentations.

Table 12: Emissions by source in Norway for the year 1992. Unit 1000 tonnes per annum.

Sources	Sulphur dioxide	Nitrogen oxides	Carbon monoxide
Total	37	220	849
Mobile sources	9	176	682
Road transport	3	79	638
Water transport	4	80	6
Other mobile sources	1	17	37
Stationary combustion	8	37	121
Industrial processes	20	7	46

These results can also be presented as histograms or pie diagrams as shown in Figure 57a.

Total emission inventories can be presented by categories and as a function of time. The development in time, related to international agreements or local goals and requirements may be another way of presenting emission data as shown in Figure 57b.



Source: SN and SFT

Figure 57: CO_2 emissions in Norway given a) by source b) as a function of time from 1960-1994.

For emissions for specified sources where the source location is given on a gridded map, the emission inventory can be given on a geographical information system (GIS), as shown in Figure 58.

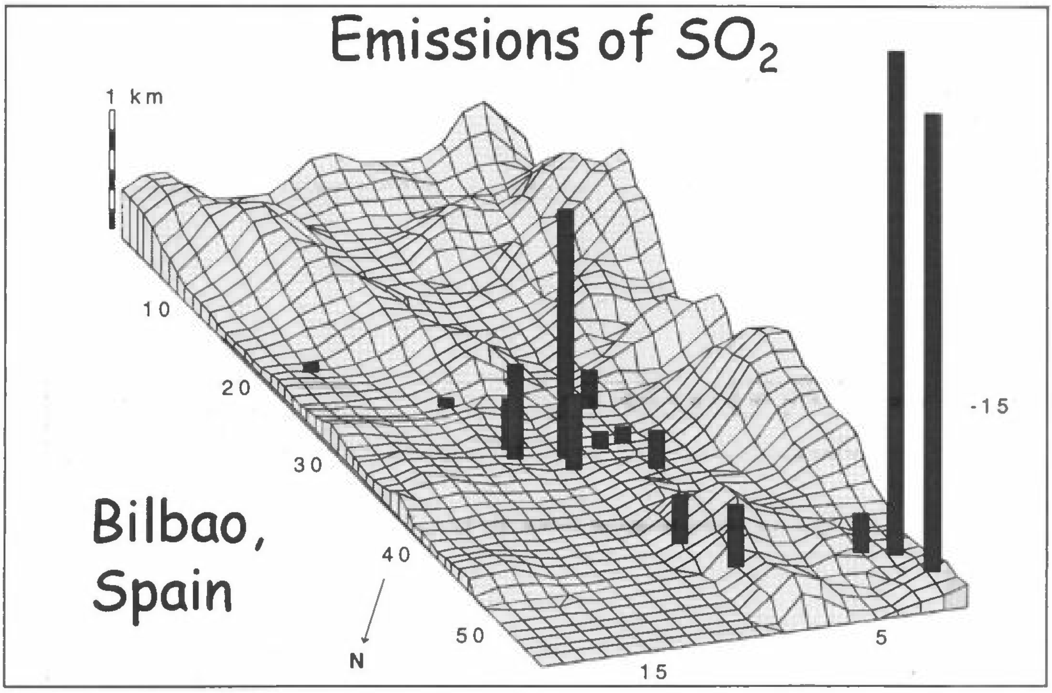


Figure 58: Gridded emission data for SO_2 emissions in a 1 km × 1 km grid for the Bilbao area in Spain. Unit kg/hour.

Another example of emission data presented in a grid is shown in Figure 4 in Chapter 2.

7.3 Meteorological data

A number of different procedures are available to handle and present measured air quality and meteorological data statistically. The most commonly used statistical methods for presentation of meteorological data:

- Time series of selected meteorological variables,
- wind roses (wind direction frequency distribution),
- different types of frequency distributions,
- joint frequency distribution to establish the relationships between wind direction, wind speed, atmospheric stability and/or other variables,.
- different types of scatter plots to establish connections between different parameters collected at the same site or at different measurement sites,
- frequency distribution of stability or other meteorological data as a function of time of day and time of year (seasonal)

The presentation of measured meteorological data is of great importance to understand the physical properties of the local atmospheric conditions. A presentation of any kind of data is helpful to visualize to the user the most important features of the data and of the meteorology and climatology of the area. It is therefore important to choose a representative tool.

In this chapter the attention will be drawn towards the different methods available for presenting meteorological data. The examples shown will not cover all possible ways of presenting results from meteorological measurements, but will introduce the reader to presentation tools most frequent used.

7.3.1 Measurements of wind speed and wind direction

Results from wind measurements are usually presented in the form of frequency distributions. Frequency distributions are either presented as matrixes (wind speed versus wind direction) or as i.e. wind roses. Wind roses are used to visualize frequency distribution of wind speed versus wind direction for different measurement stations.

Figure 59 presents wind roses for a winter season at two sites located about 30 km apart.

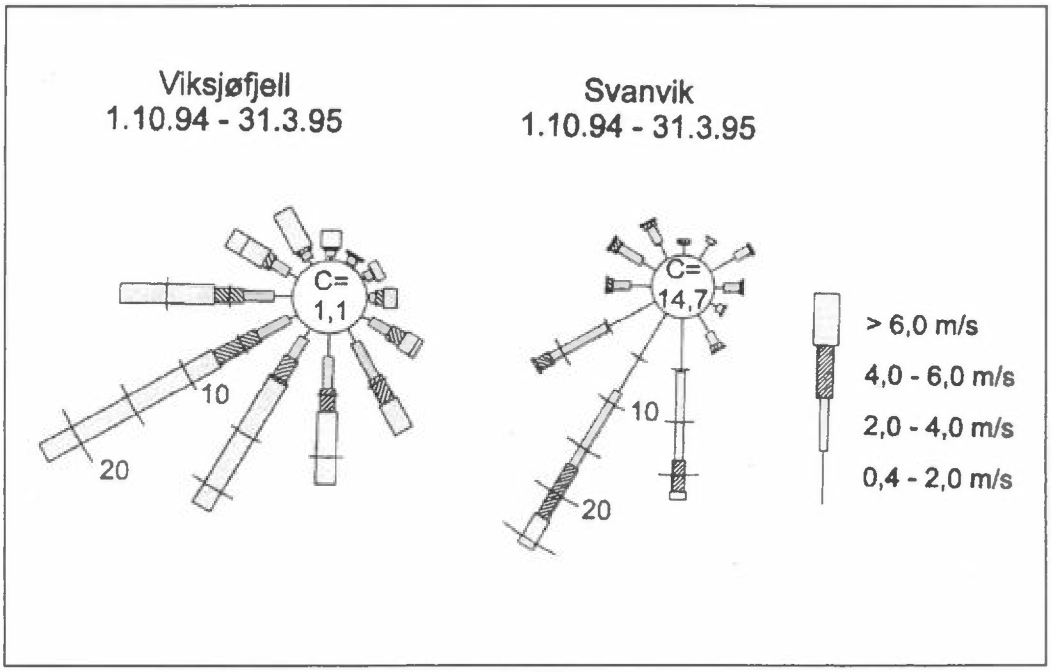


Figure 59: Wind roses for two different measurement sites; Viksjøfjell at hill top (low friction), Svanvik in a valley (high surface roughness) (Hagen et al., 1996).

The wind roses shows the frequency of wind in 12 30 degree-sectors, i.e. how often the wind blows from the different directions. The frequency distributions are given for the following sectors: north (360°) (i.e. 360 ±15°), north-north-east (30°), east-north-east (60°), east (90°), east-south-east (120°), south-south-east (150°), south (180°), south-south-west (210°), west-south-west (240°), west (270°), west-north-west (300°) and north-north-west (330°). The symbol C in the middle of the wind rose gives the percentage of calm weather. Calm conditions refers to hourly wind speeds less than 0.4 m/s.

The wind roses in Figure 59 shows that winds from west-south-west were most frequent at Viksjøfjell.

Winds from south and south-west were most frequent during the winter season at Svanvik. The wind speeds were much lower at Svanvik, due to more friction at the surface in the valley. The frequency of calm weather was 1.1% during winter at Viksjøfjell, and 14.7% during winter at Svanvik.

Sometimes it might be useful to compare the wind direction distribution at different meteorological measurement stations to get an indication of the representativeness of each of the stations for a larger area. Wind roses for the individual measurement stations can then be presented on a map as shown below.

Figure 60 presents wind roses for 1990 from Kirkenes Airport, Viksjøfjell, Svanvik, Nikel and Janiskoski.

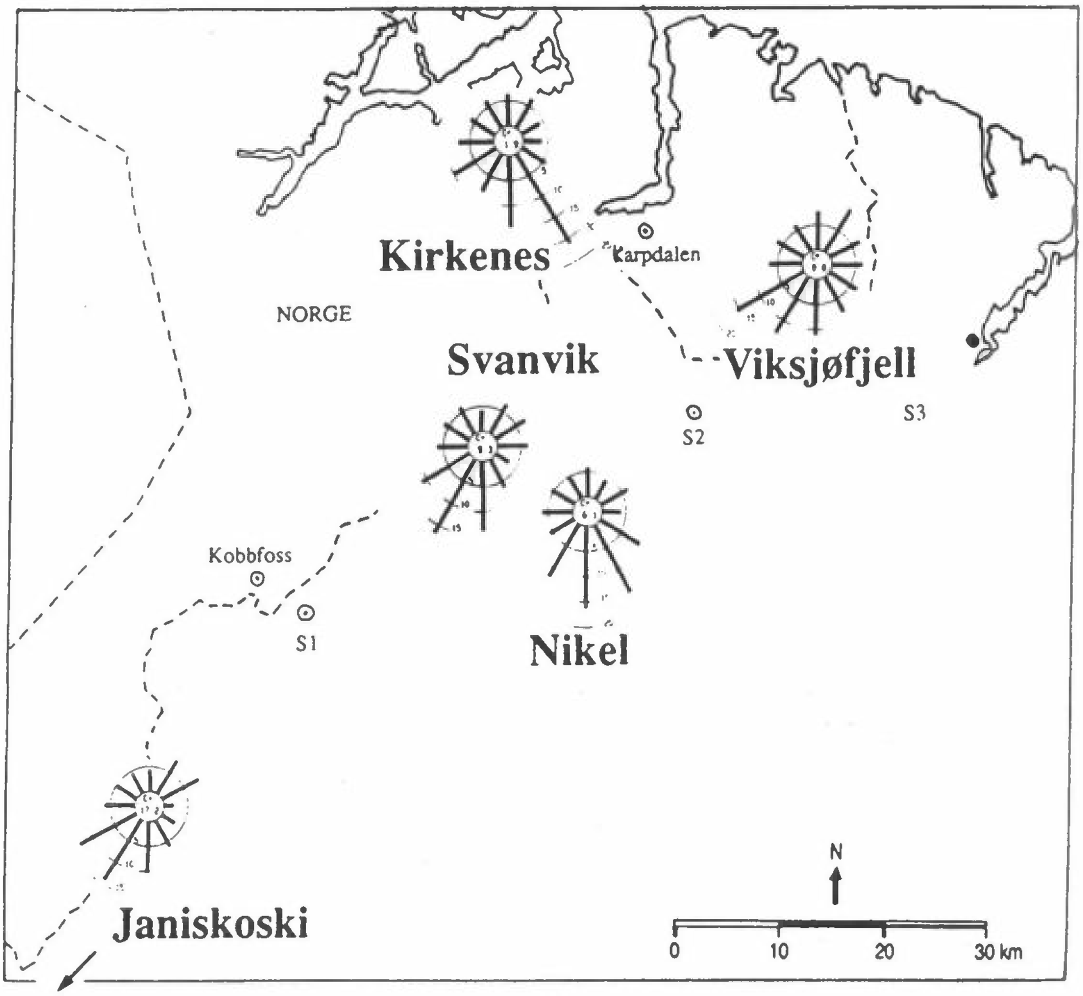


Figure 60: Wind roses for Kirkenes Airport, Viksjøfjell, Svanvik, Nikel and Janiskoski for 1990 (Sivertsen et al. 1991).

The mean wind speed may also be presented as a function of wind direction as shown in 61. The mean wind at Ullevål in Oslo during February 1996 was 1.5 m/s. The highest average speed of 2.0 m/s occurred at winds from east and the lowest average speed of 0.7 m/s was with wind from north-north-west. This indicate a channelling of winds from along north-east and around south-west. The distribution is important for evaluation of air pollution dilution.

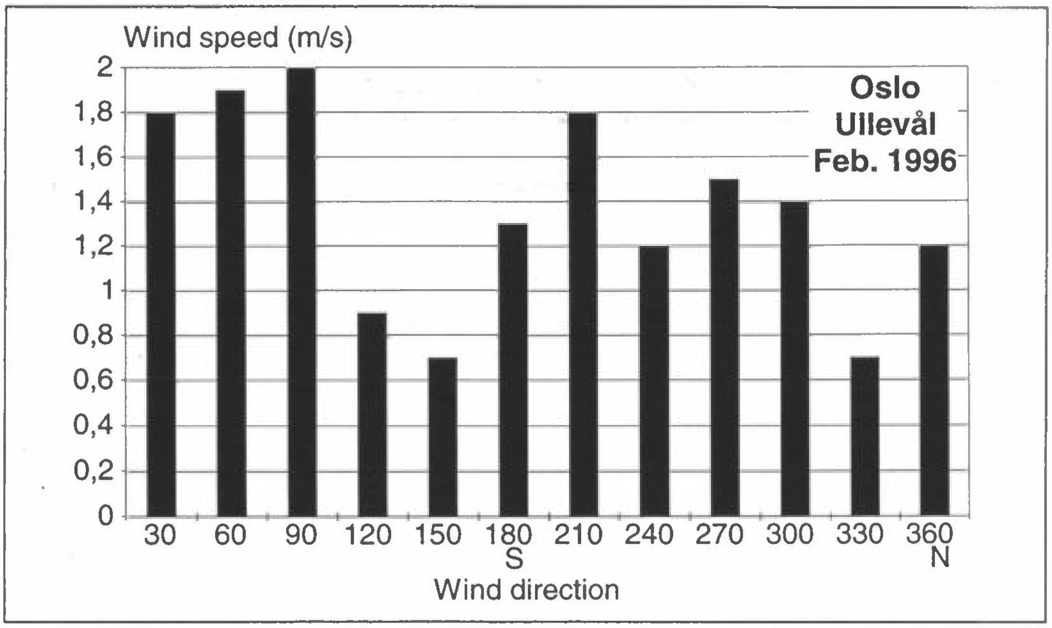


Figure 61: Mean wind speed as a function of wind direction at Ullevål, Oslo, February 1996.

7.3.2 Measurements of temperature

Figure 62 presents the monthly distribution of hourly averaged air temperatures at Viksjøfjell and Svanvik (meteorological measurement stations in the northern part of Norway) for the period 1.1.1990-31.3.1991. The figure gives the maximum temperature (highest hourly mean), mean maximum temperature, monthly mean temperature, the 50-percentile (50% of the hourly mean values are higher and lower than this value respectively), mean minimum temperature and minimum temperature (lowest hourly mean).

The figure shows that the difference between summer and winter was more pronounced at Svanvik compared to Viksjøfjell. The height above sea level and higher mean wind speeds at Viksjøfjell explains the lesser temperature variation at this site.

Data are missing at Viksjøfjell for the period late November to mid-January 1991 because of problems with the data logger.

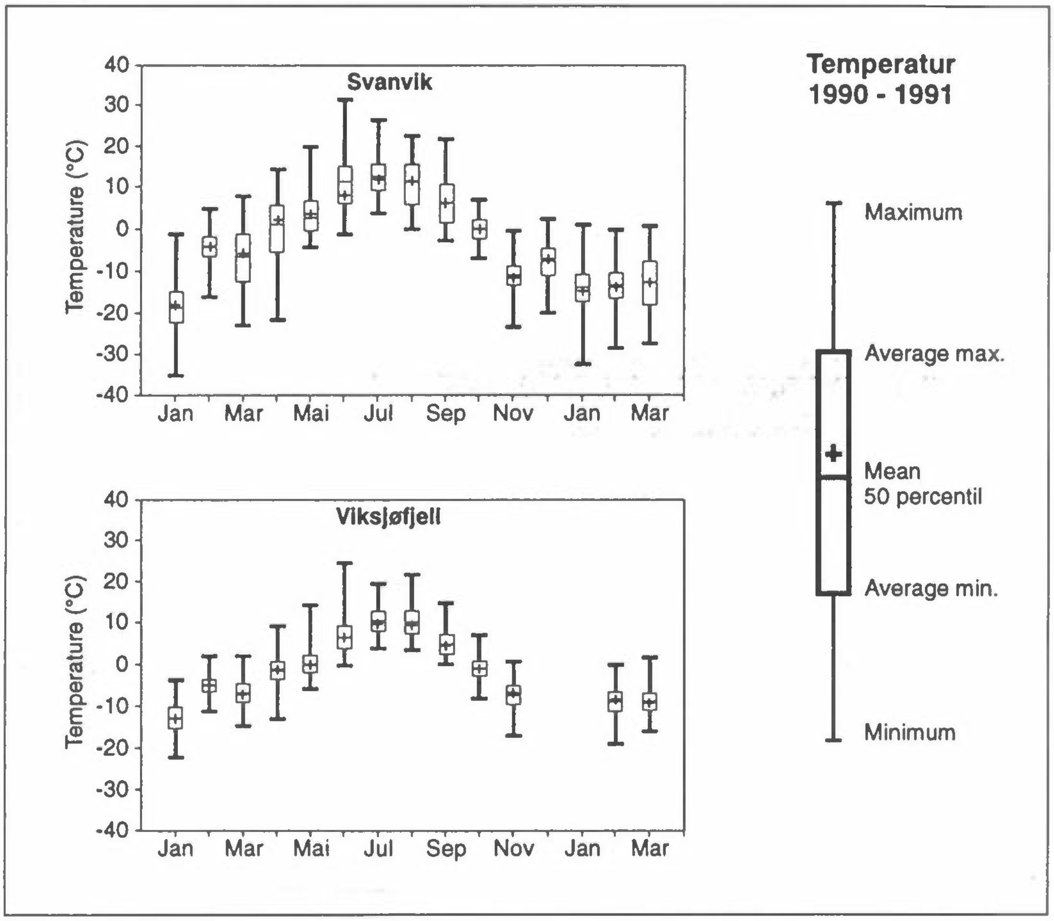


Figure 62: Temperature statistics for Viksjøfjell and Svanvik for every month during the period 1.1.1990-31.3.1991 (°C) (Sivertsen et al. 1991).

7.3.3 Atmospheric stability and turbulence

The thermal stability of the atmosphere is an important factor for the vertical dilution of air pollution. The stability is measured as the vertical temperature gradient of the atmosphere, and is also a measure of thermally induced turbulence. The turbulence is given by the small scale fluctuations in the wind and is a measure for the dilution of air pollutants.

The atmospheric stability in this example is measured at Viksjøfjell as the temperature difference (ΔT) between 2 m a.s.l. and 10 m a.s.l. The measured temperature differences are divided into 4 classes. Each of these 4 classes indicate the stability of the atmosphere and hence, the vertical dilution of air pollutants. The classes are:

Unstable	$\Delta T \leq -0.5\ ^{\circ}C$
Neutral	$-0.5\ ^{\circ}C < \Delta T \leq 0.0\ ^{\circ}C$
Light stable	$0.0\ ^{\circ}C < \Delta T \leq 0.5\ ^{\circ}C$
Stable	$0.5\ ^{\circ}C < \Delta T$

Neutral atmospheric stability (often characterized by strong winds and cloudy conditions) and unstable atmospheric stability usually results in good dispersion of air pollutants emitted into the atmosphere.

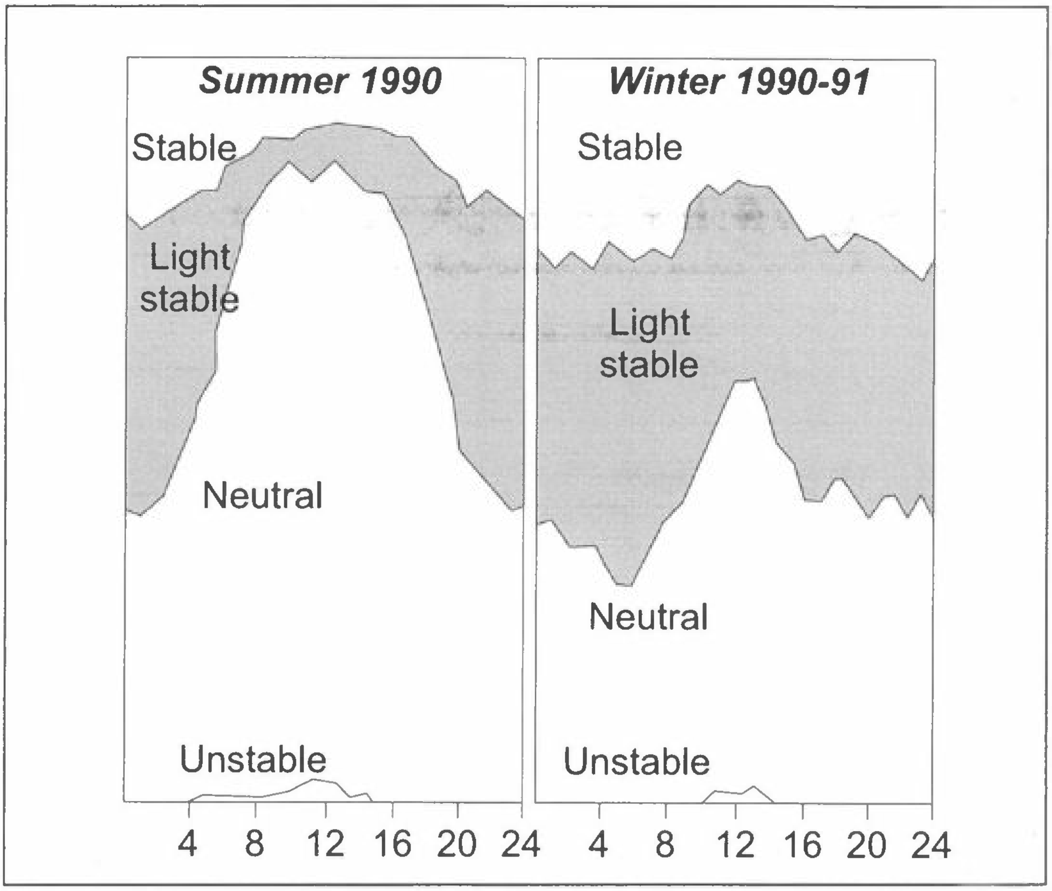


Figure 63: Frequency distribution of the four stability classes at Viksjøfjell as 24 h averages during the summer and winter season. (Sivertsen et al. 1991).

During night-time and winter when there is a net outgoing radiation from the earth, the ground cools off rapidly resulting in cold air at the surface and a temperature increase with height (light stable /stable or inversions). An inversion layer is formed, and the dispersion of pollutants is suppressed.

Figure 63 shows the frequency distribution of the four stability classes at Viksjøfjell for the winter seasons 1989/90 and 1990/91 and for the summer season 1990. The figure indicates a fairly low frequency of unstable weather, mostly during daytime and summer. Inversions, or stable atmospheric conditions, occurred approximately 50% of the time in the winter season, more frequent during daytime than during night. During the summer, inversions occurred in approximately 30% of the time. At night time hours it was about 50% inversion, at daytime only 15%. Near neutral atmospheric conditions were most frequent during summer, noticeably during mid-day (approximately 90% of the time).

The figure also indicate that the vertical dispersion of air pollutants is better during the summer season than during the winter season, especially during daytime.

Table 13 shows another way of presenting the frequency distribution of the four stability classes given for each season and averaged for one year.

Table 13: The frequency (in %) of unstable, neutral, light stable and stable atmospheric conditions at ground level measured at Brenntangen (Norway).

	Spring	Summer	Fall	Winter	Year
Unstable	18	42	11	0	18
Neutral	46	49	50	8	38
Light stable	29	8	32	77	36
Stable	7	1	7	15	8

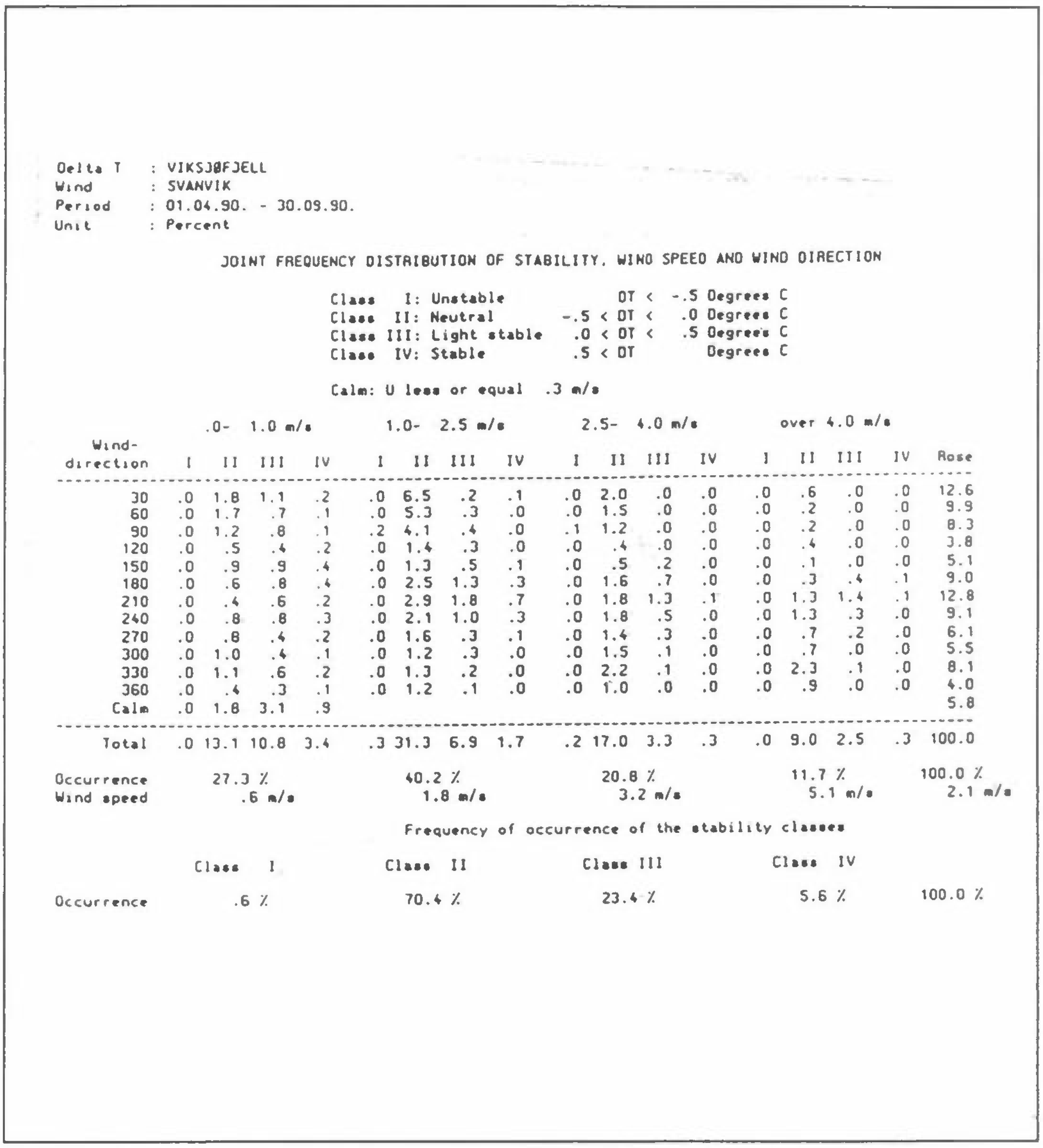
7.3.4 The combined wind-/stability matrix

The wind frequency distribution and the atmospheric stability may be combined in a wind-/frequency matrix (Table 14). The matrix gives the meteorological conditions at the specific measurement station as a function of

- four stability classes,
- four wind speed classes,
- twelve wind direction classes.

The right column of Table 14 is the basis for the wind rose presented in Figure 60. The meteorological frequency matrix is an important input to one of the Gaussian air pollution dispersion models utilized and produced by NILU.

Table 14: *Frequency distribution of wind and stability for 4 stability classes, 4 wind speed classes and 12 wind direction classes (%) for Viksjøfjell 1.10.1989-31.3.1990 (Sivertsen et al. 1991).*



```
Delta T    : VIKSJØFJELL
Wind       : SVANVIK
Period     : 01.04.90. - 30.09.90.
Unit       : Percent

              JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

                             Class   I: Unstable            DT <  -.5 Degrees C
                             Class  II: Neutral        -.5 < DT <   .0 Degrees C
                             Class III: Light stable    .0 < DT <   .5 Degrees C
                             Class  IV: Stable          .5 < DT        Degrees C

                             Calm: U less or equal  .3 m/s

                  .0-  1.0 m/s        1.0-  2.5 m/s       2.5-  4.0 m/s        over 4.0 m/s
   Wind-
 direction    I   II  III   IV      I   II  III   IV      I   II  III   IV      I   II  III   IV   Rose
---------------------------------------------------------------------------------------------------------
       30    .0  1.8  1.1   .2     .0  6.5   .2   .1     .0  2.0   .0   .0     .0   .6   .0   .0   12.6
       60    .0  1.7   .7   .1     .0  5.3   .3   .0     .0  1.5   .0   .0     .0   .2   .0   .0    9.9
       90    .0  1.2   .8   .1     .2  4.1   .4   .0     .1  1.2   .0   .0     .0   .2   .0   .0    8.3
      120    .0   .5   .4   .2     .0  1.4   .3   .0     .0   .4   .0   .0     .0   .4   .0   .0    3.8
      150    .0   .9   .9   .4     .0  1.3   .5   .1     .0   .5   .2   .0     .0   .1   .0   .0    5.1
      180    .0   .6   .8   .4     .0  2.5  1.3   .3     .0  1.6   .7   .0     .0   .3   .4   .1    9.0
      210    .0   .4   .6   .2     .0  2.9  1.8   .7     .0  1.8  1.3   .1     .0  1.3  1.4   .1   12.8
      240    .0   .8   .8   .3     .0  2.1  1.0   .3     .0  1.8   .5   .0     .0  1.3   .3   .0    9.1
      270    .0   .8   .4   .2     .0  1.6   .3   .1     .0  1.4   .3   .0     .0   .7   .2   .0    6.1
      300    .0  1.0   .4   .1     .0  1.2   .3   .0     .0  1.5   .1   .0     .0   .7   .0   .0    5.5
      330    .0  1.1   .6   .2     .0  1.3   .2   .0     .0  2.2   .1   .0     .0  2.3   .1   .0    8.1
      360    .0   .4   .3   .1     .0  1.2   .1   .0     .0  1.0   .0   .0     .0   .9   .0   .0    4.0
     Calm    .0  1.8  3.1   .9                                                                     5.8
---------------------------------------------------------------------------------------------------------
    Total    .0 13.1 10.8  3.4     .3 31.3  6.9  1.7     .2 17.0  3.3   .3     .0  9.0  2.5   .3  100.0

Occurrence      27.3 %              40.2 %              20.8 %              11.7 %          100.0 %
Wind speed        .6 m/s             1.8 m/s             3.2 m/s             5.1 m/s          2.1 m/s

                                 Frequency of occurrence of the stability classes

               Class   I          Class  II           Class III           Class  IV

Occurrence        .6 %              70.4 %              23.4 %               5.6 %          100.0 %
```

7.3.5 Precipitation

A graphical presentation of precipitation rates, precipitation intensity and precipitation as a function of wind direction is useful if calculations of wet removal depositions are to be performed. An example of such a presentations is shown below in Figure 64.

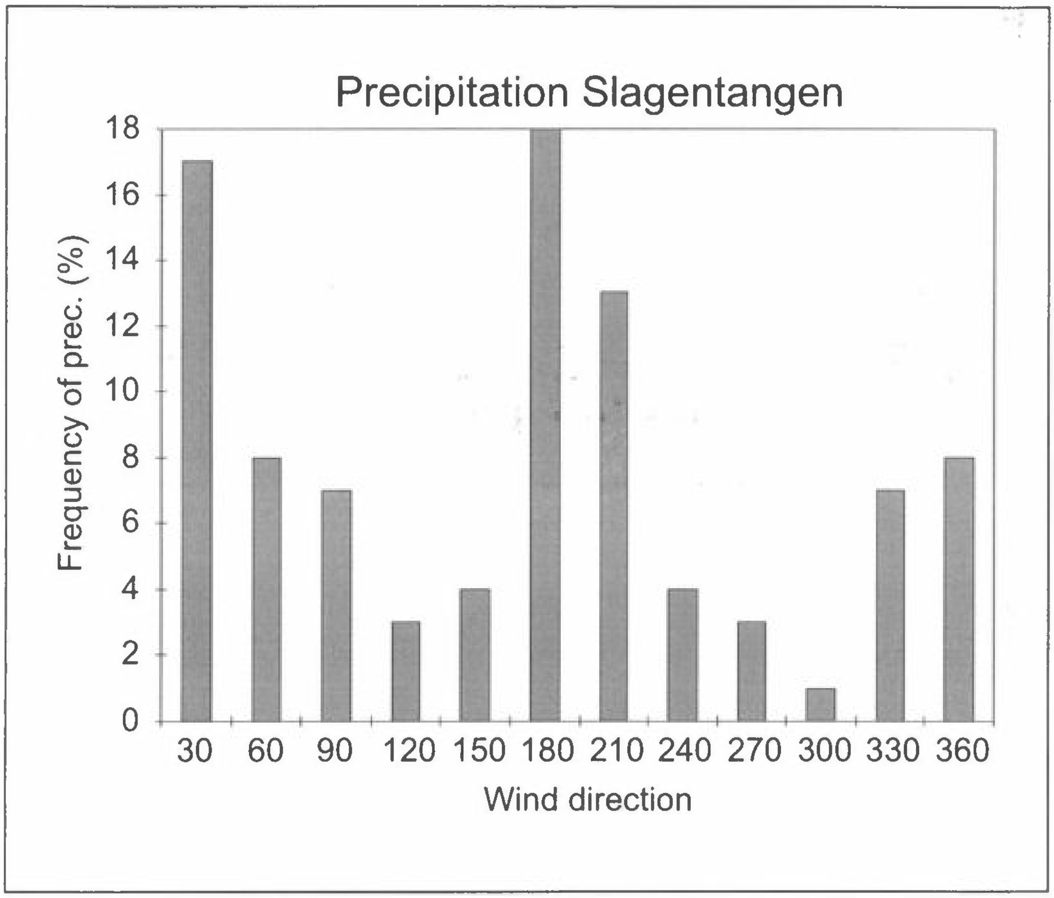
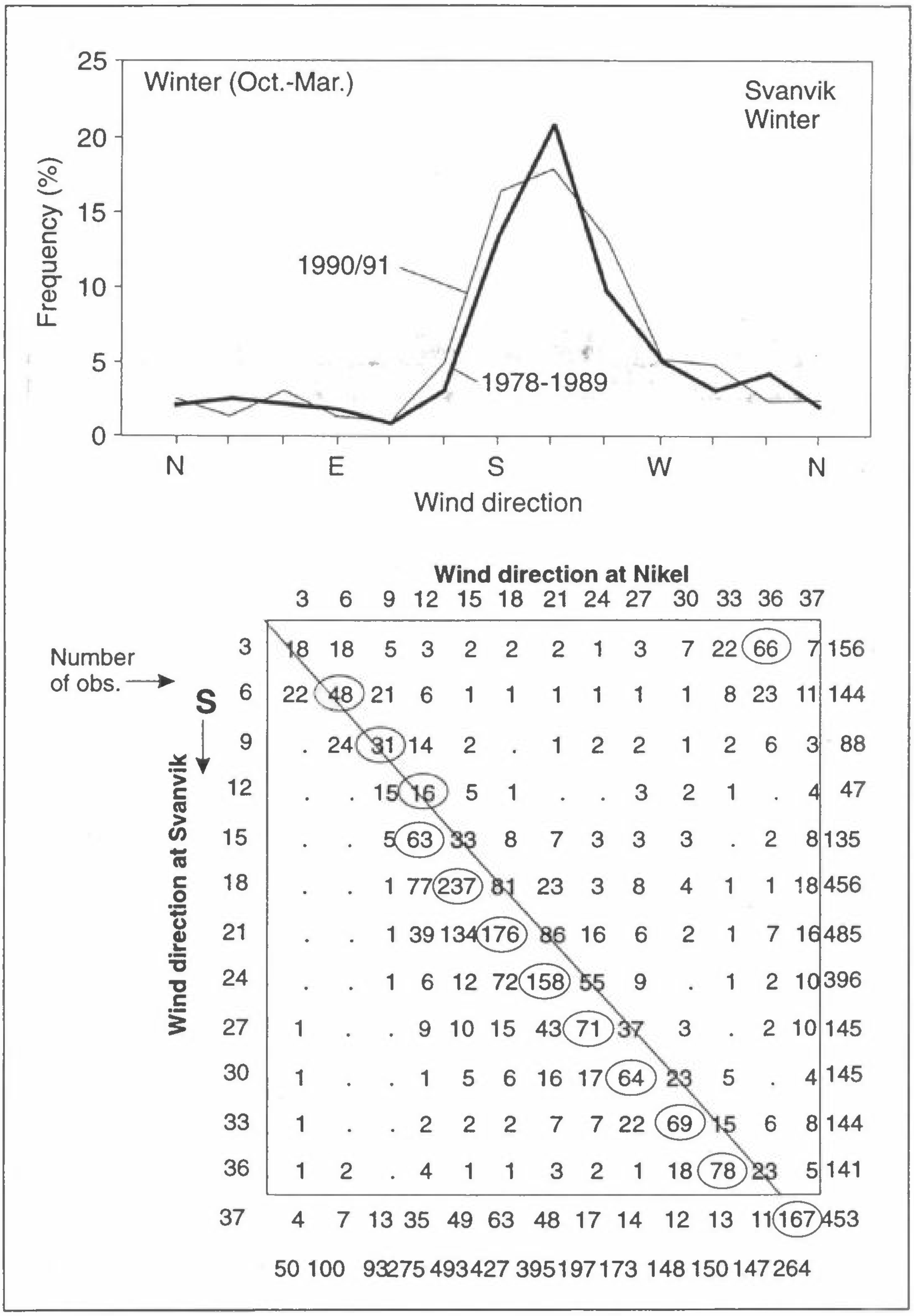


Figure 64: Precipitation as a function of wind direction at Slagentangen, Norway (1961-69) (Sivertsen et al. 1990).

7.3.6 The representativity of the wind measurements

NILU has performed wind measurements at Svanvik since fall 1978. Figure 65a presents wind frequency distributions for 12 30° sectors for the winter season 1990/91 compared to the long-term average for the winter seasons 1978-89. The frequency distributions compare well, at the data collected during 1990/91 can be considered representation or typical for this site.

A comparison of frequency distributions collected at two different sites is presented in Figure 65b. If all data were clustered along the diagonal one station would perfectly represent the other. In this case it can be seen that the wind at Nikel has a tendency of blowing to the left of that at Svanvik. Wind from south at Nikel give simultaneously wind from south-south-west at Svanvik.



	3	6	9	12	15	18	21	24	27	30	33	36	37	
3	18	18	5	3	2	2	2	1	3	7	22	66	7	156
6	22	48	21	6	1	1	1	1	1	1	8	23	11	144
9	.	24	31	14	2	.	1	2	2	1	2	6	3	88
12	.	.	15	16	5	1	.	.	3	2	1	.	4	47
15	.	.	5	63	33	8	7	3	3	3	.	2	8	135
18	.	.	1	77	237	81	23	3	8	4	1	1	18	456
21	.	.	1	39	134	176	86	16	6	2	1	7	16	485
24	.	.	1	6	12	72	158	55	9	.	1	2	10	396
27	1	.	.	9	10	15	43	71	37	3	.	2	10	145
30	1	.	.	1	5	6	16	17	64	23	5	.	4	145
33	1	.	.	2	2	2	7	7	22	69	15	6	8	144
36	1	2	.	4	1	1	3	2	1	18	78	23	5	141
37	4	7	13	35	49	63	48	17	14	12	13	11	167	453
	50	100	93	275	493	427	395	197	173	148	150	147	264	

Figure 65: The representativity of the wind frequency distribution: a) measured at Svanvik during the winter 1990/91 compared to the long term mean for the winter seasons; b) simultaneously observed wind directions at two measurement sites (Nikel and Svanvik) to identify differences and representativity.

7.4 Air quality data

7.4.1 Trends, changes in time

The presentation of selected air quality indicators as a function of time is a helpful tool in understanding time variations in emissions and dispersion conditions. Analyzing the time variation at several measurement sites, as presented in Figure 66, shows typical seasonal differences at one site compared to another.

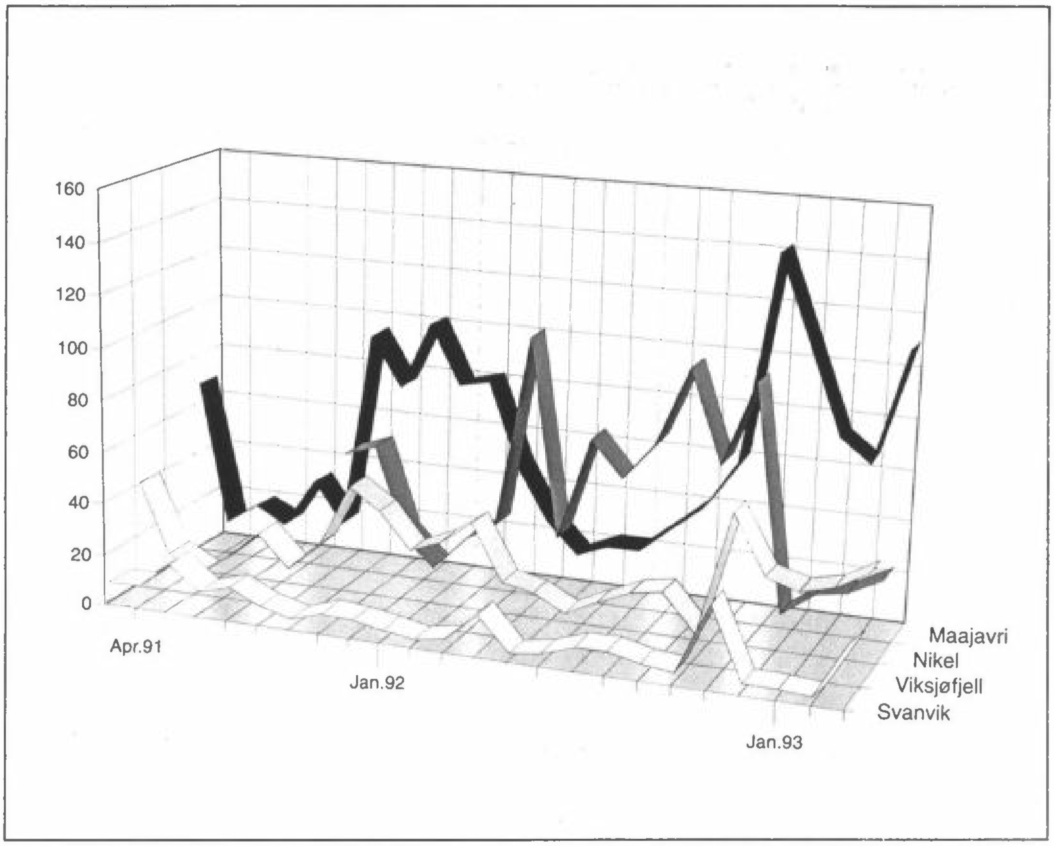


Figure 66: The variation in time of monthly SO_2-concentrations at 4 measurement sites from April 1991 to January 1993.

Some sites are typically impacted during the winter season, when the predominant wind transports SO_2 from a smelter complex towards the measurement site. One data set (Nikel)indicate a summer maximum. This site is located downwind from the smelter during predominant summer wind directions.

Box plots have been used by OECD-countries as an advanced air quality trend indicator. A typical box plot is shown in Figure 67.

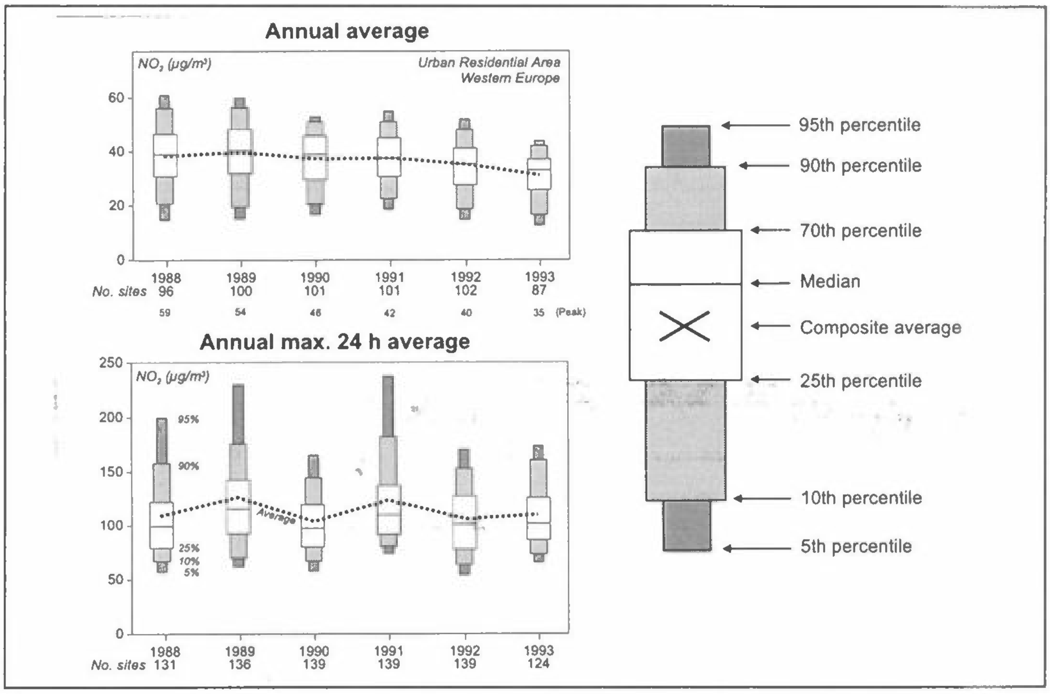


Figure 67: An OECD trend analysis presenting annual NO_2 data (average and max. 24 h average) from 1988 to 1993 from up to 139 measurement sites in Western Europe.

The box plot represents a uniform method for pollutant specific (indicator) air quality trends reporting. It increases the comparability, it can present national or international wide trends and represents a standardized reporting procedure.

Boxplot diagrams have been generated for several combinations of regions, site categories and defined pollutant indicators. In cases of insufficient monitoring sites, or unavailability of data, the establishment of trend can be difficult.

From the Norwegian Surveillance programme, operated by NILU for the Norwegian Pollution Control Authority, a simplified trend analysis is presented in Figure 68.

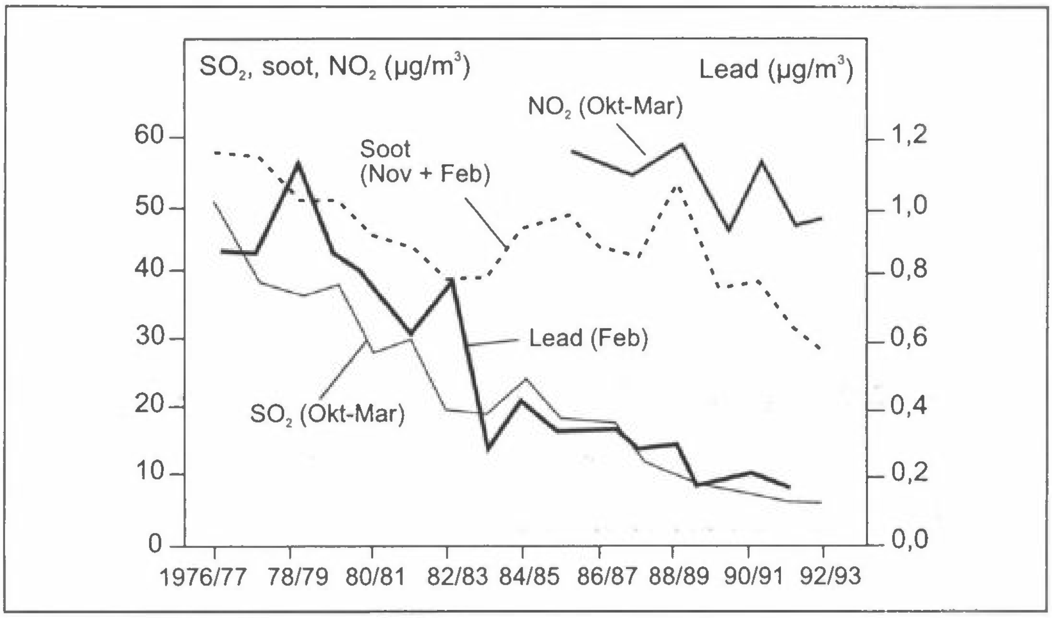


Figure 68: Air quality trends as an average for 8 selected urban areas in Norway (1977-94).

Data from 8 selected cities in Norway have been used to demonstrate the long term trend of SO_2, soot, lead and NO_2 in Norway over the past 20 years as shown in Figure 68. The figure shows the development in time of the winter average concentrations since 1976/77. The Norwegian air quality guideline values are specified for 6 month winter averages. Hence, data presentations often mainly contain winter average concentrations. Studied have also been performed to look at the differences between summer and winter averages, as shown in Figure 69.

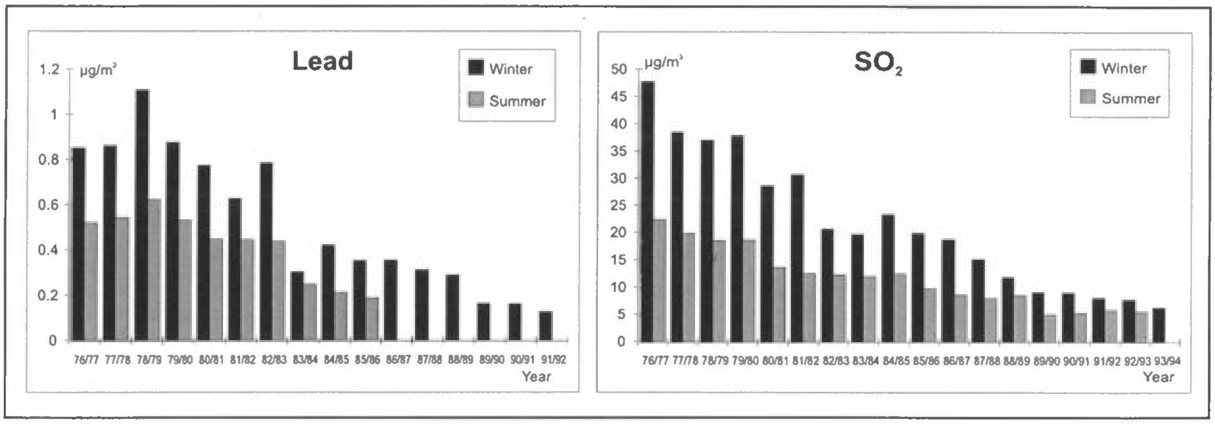


Figure 69: Long term trends of winter and summer average lead and SO_2 concentrations in Norway.

The significant reduction in SO_2 levels has been caused by a shift to lighter and sulphur poor fuel oils and a steady change to using hydro electric power for home heating. The reduction in lead concentrations is partly caused by the introduction of unleaded gasoline since 1983 and lowering the lead content in all gasoline since 1980.

The levels of soot and suspended particles decreased due to the reduced use of heavy fuel oil until 1983. After that time most of the suspended particles in Norwegian cities originate from automobile traffic emissions. The traffic also causes high concentrations of NO_2 especially during cold winter days with strong surface inversions. NO_2 is at present, together with PM_{10}, the main local air pollution problem in Norway.

7.4.2 Peak statistics

The levels of air pollution in cities within the OECD region have been evaluated by constructing peak statistic bar charts (OECD, 1996). The bar charts show the range of concentrations measured by monitors within the city for defined indicators (e.g., annual maximum 1-hour nitrogen dioxide). The bar charts show the highest, composite average and lowest values of annual maximum values for each defined indicator as segments of a bar. For example: The bar chart for annual maximum 1-hour nitrogen dioxide shows the highest, lowest and composite average concentration of the maximum 1-hour nitrogen dioxide concentration recorded by monitoring sites located in the city.

The principal objective of the bar charts is to enable the comparison of air quality in large cities of Member countries, to indicate where concentrations are likely to result in acute health effects to show country-wide, regional and OECD-wide statistics. An example urban peak statistic bar chart is shown in Figure 70.

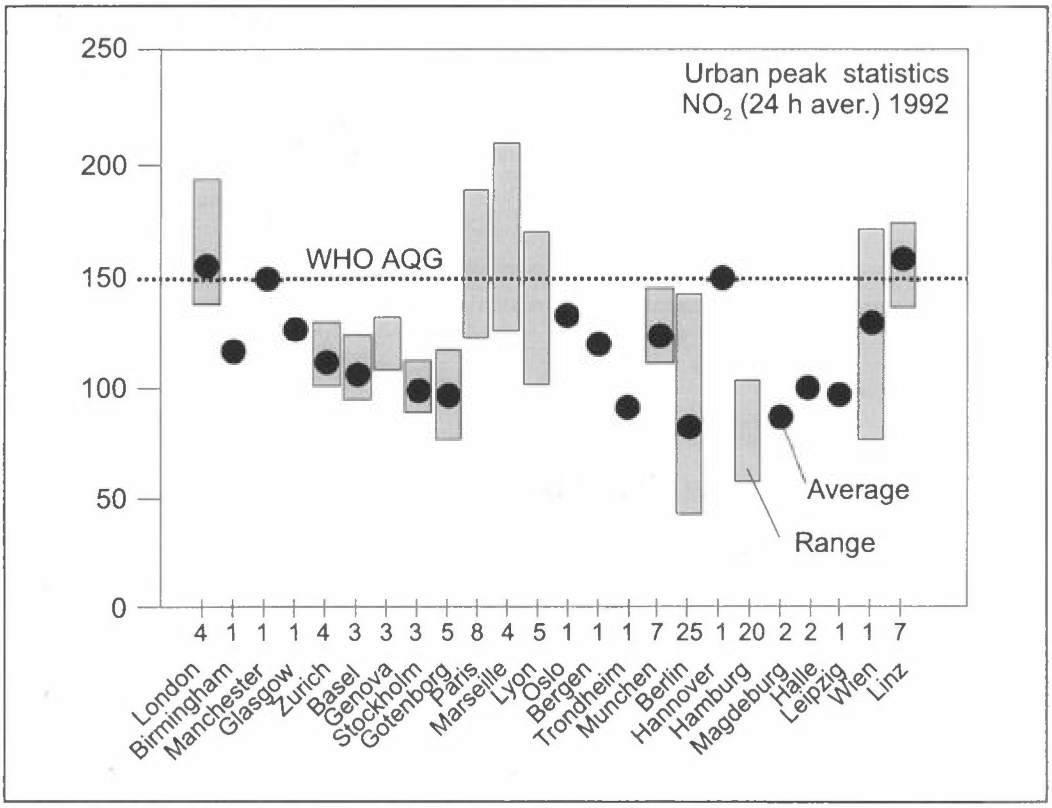


Figure 70: Example of an urban peak statistics bar chart taken from the OECD study (OECD, 1996)

7.4.3 Spatial concentration distribution

When a large number of measurement site data are available it is possible to present a spatial concentration distribution based upon statistical averaging procedures. Such a distribution is shown in

Figure 71 for a diurnal average NO_2-concentration measured in the Helwan area in Egypt.

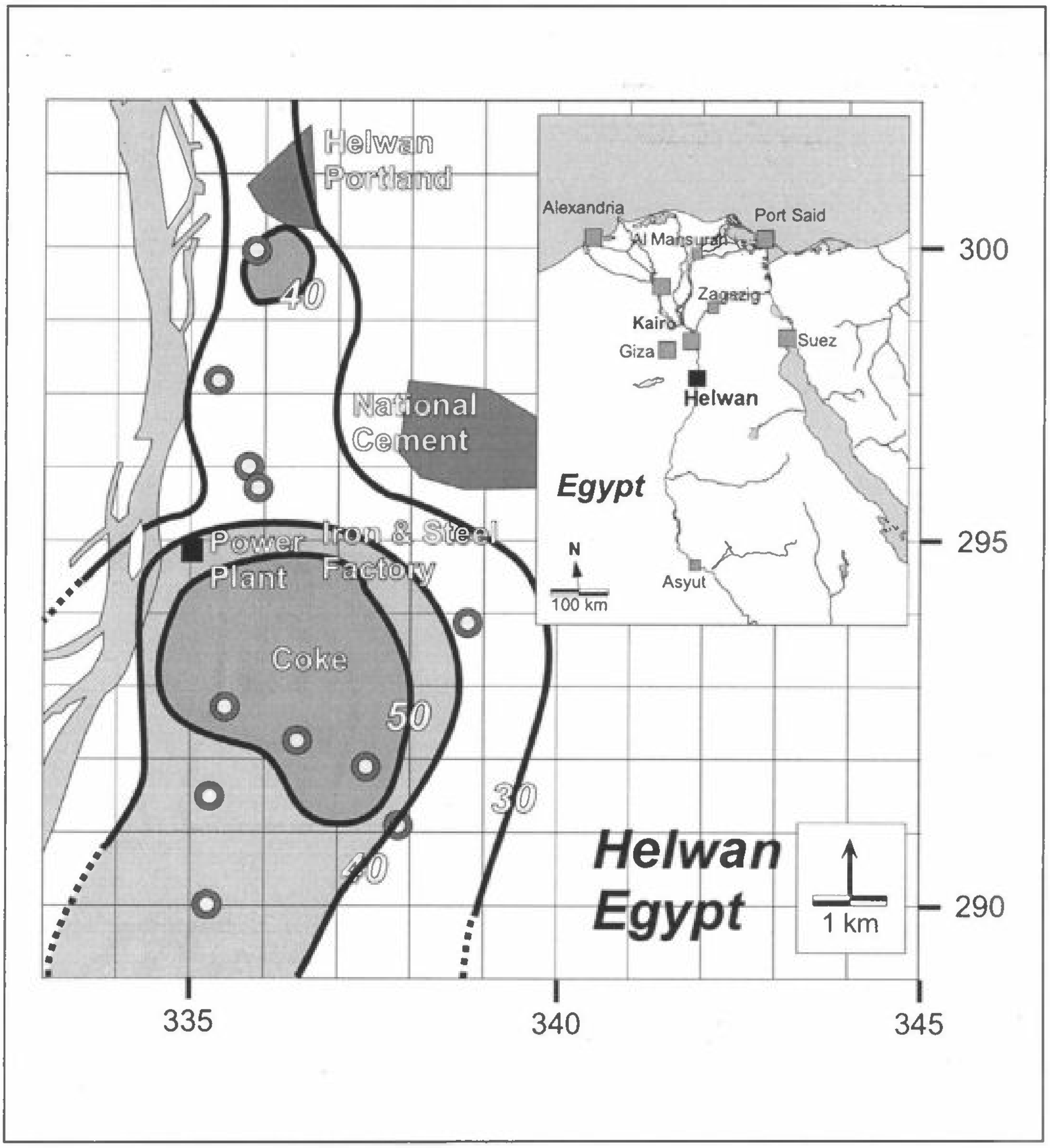


Figure 71: Concentration distribution of SO_2 measured as a weekly average using simple inexpensive passive samplers.

The specific distribution presented in Figure 71 was measured as a SO_2 screening study to find the maximum impacted areas. SO_2 concentrations were measured as weekly averages using inexpensive passive samplers. The simple screening study indicated weekly SO_2 averages of up to 50 µg/m³ downwind from major industrial areas.

The number of measuring sites available for data interpolation are normally too few to generate a picture like the one presented in

Figure 71. However, measurements together with modelling results have frequently been used for this purpose. several examples can be given. Figure 72 represents a combination of measurement data and model results.

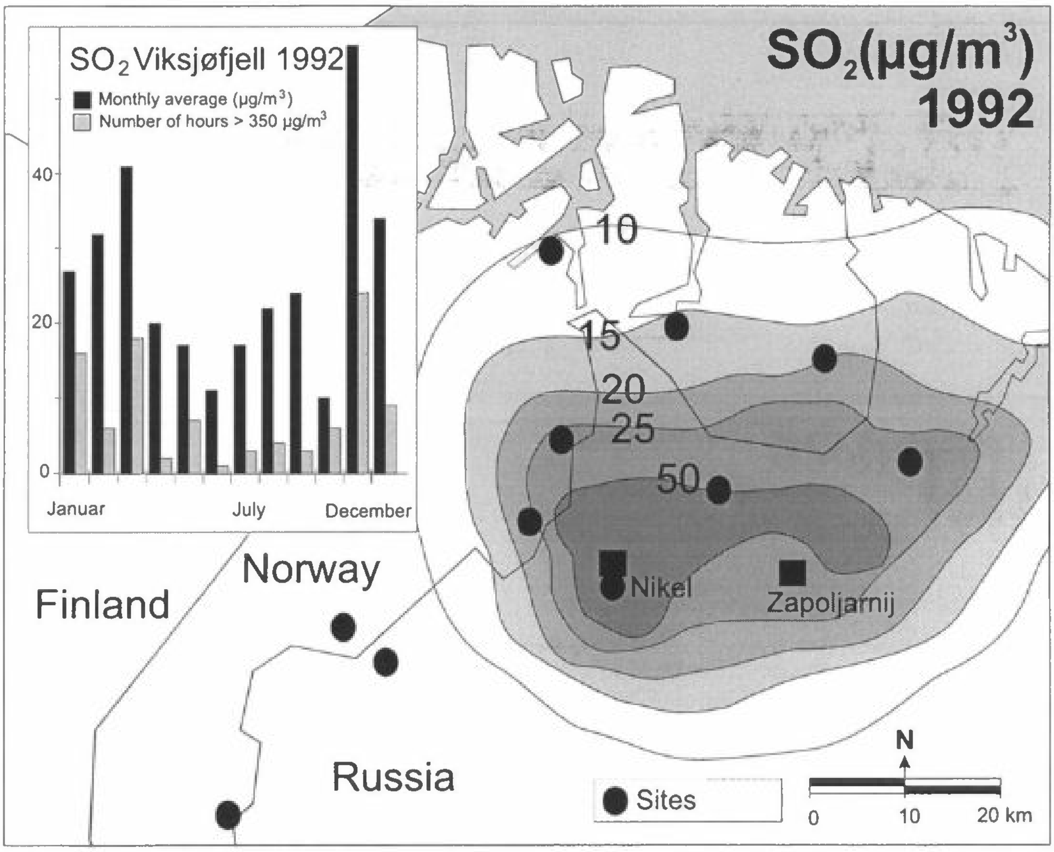


Figure 72: Seasonal model estimated average SO_2 concentration distribution, and observed monthly mean and number of AQG exceedances at one site in the area.

The last example of data presentation is based on a Geographical Information System (GIS) platform. Concentration distributions may be based upon data from individual measuring sites, interpolated concentration fields presented on a map or GIS platform linked to an air pollution dispersion modelling system (see AirQUIS).

Figure 73 presents the data from background measurements and estimates of sulphur and nitrogen deposition in Norway.

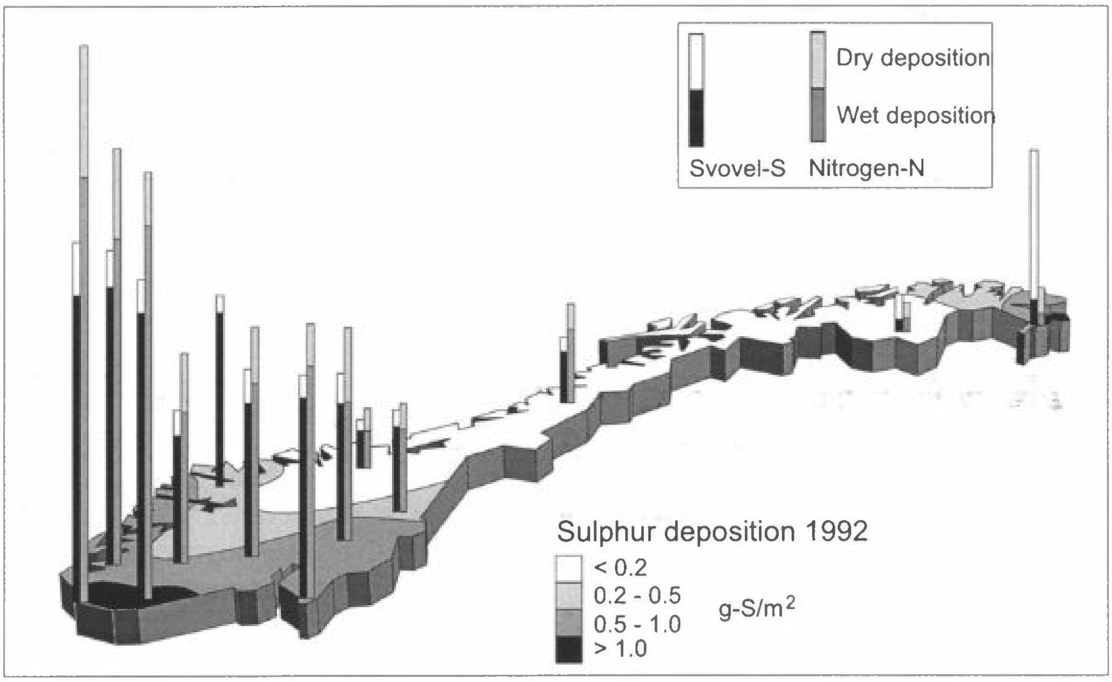


Figure 73: Dry and wet deposition of sulphur and nitrogen in Norway

A total of 42 background stations were operated in Norway in 1993 to map the rural and background concentrations in air and precipitation of various pollutants. Long range transport of acidifying compound is recognized to be among the most severe environmental problems in Norway. measurements and model estimates show that the highest concentrations of sulphur and nitrogen components occur in the southern and south-western part of Norway (Tørseth and Joranger, 1994).

7.4.4 Presentation of estimated concentration distributions

Results from the use of air pollution dispersion models can be presented in many ways.

Concentrations from the use of a steady state Gaussian model was presented as a function of distance from the source in Figure 51. It is possible to present the results for many wind speeds and many stabilities.

The spatial concentration distribution as a result of estimates applying a three dimensional numerical model is presented in Figure 74.

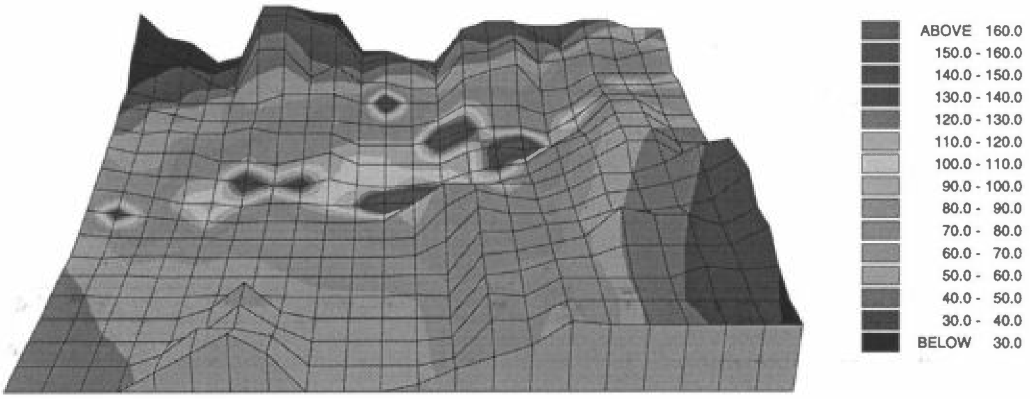


Figure 74: Estimated short term (1 h-average) ground level concentrations of NO_2 estimated for the urban area of Oslo. These estimates are performed every hour of the year based upon on-line meteorological data as input.

The 1 h average NO_2 concentrations shown in Figure 74 may be estimated every hour of the year if required. These types of advanced modelling results have been used as input to exposure estimates, based on the estimates of NO_2 concentrations in selected microenvironments. Urban scale models of this type are also important for planning purposes, impact assessment and air quality short time forecasts.

7.5 User friendly presentation

Several users of environmental data will represent different needs for information. During the last few years developments have included more user friendly presentations. These have been produced to meet the requirements from:

- specialists on air pollution,
- policy makers and
- public.

The ***specialist*** often needs a tool that gives easy access to the data with the ability to treat these data in different ways. The specialist also want to apply the data and prepare his own way of presenting results graphically.

The ***policy makers*** need presentations that illustrates the conclusions that the specialist have drawn from the information available. This is usually best done through a graphical presentation.

The ***public*** needs information on the general state of the environment. The type of information that is needed is more general than that of the policy maker. It often needs to cover environmental issues that is of special concern to the public. This could be the air quality that is expected to occur in the urban area on this specific day. This information could be given as a short term forecast or based upon actual on-line data.

The information may be multimedia: texts, tables, graphs, images, sound or video dependent on the end user. The presentations have to be designed to meet the user needs.

The information to the policy makers should be summaries and annual reports. These reports should contain of the work that have been done during the time period in question and the results should be presented in tables and graphs. The tables should be in appendixes and the graphs in the main report. The reason for presenting the two is that in further use it is necessary to know the numbers and these are not very easy to take out of a graph.

The public needs information that is easily available. This could be done through leaflets, Radio forecasts of the air pollution situation in several locations. It could also be done through video screens for pollution purposes. These can give continuous up-to-date date information on air quality measured in the area. and predictions of the development.

This information is usually made from data that come from individual files on a computer. These data are processed through special computer programmes. The output of the data is presented graphically through a graphical programme. All this work have to be done by skilled personnel. This makes the data and information difficult to access.

Modern system are now developing where the data are stored in databases and the results are generated through a geographical information system. These systems makes the access to the data easy and the treatment and presentation of data easy. The user can deduct information and make graphs through automized procedures. This keeps the information available up-to-date for policy makers and the public. AirQUIS is one of these systems. AirQUIS has been based upon a GIS platform. It is easy to apply, user friendly and is, in addition to being a presentation platform, also a planning tool.

8. Impact assessment

8.1 The content of the environmental impact assessment (EIA)

The purpose of an Environmental Impact Assessment (EIA) is to determine the potential environmental, social and health effects of a proposed development. It attempts to define and assess the physical, biological and socio-economic effects in a form that permits a logical and rational decision to be made.

Attempts can be made to reduce potential adverse effects and impacts through the identification of possible alternative sites and/or processes. There is no general and universally accepted definition of the EIA. The great diversity of EIA definitions is illustrated by the following examples:

1: **Impact prediction** to determine the impact on the biogeophysical environment and on man's health and well-being as a result of legislative proposals, policies, development programmes, projects and operational procedures.
2. **Impacts and benefits** of a proposed development. The assessment needs to be communicated in terms understandable by the community and the decision-makers. Pros and cons should be identified on the basis of criteria relevant to the area affected.
3. **A total assessment** of relevant environmental and resulting social effects which may result from the fulfilling of a defined project.
4. **Establish quantitative values** for selected parameters which indicate the quality of the environment before, during and after a specified action or establishment.
5. **A systematic examination** of the environmental consequences of projects, policies, plans and programmes. Its main aim is to provide decision makers with an account of the implications of alternative courses of action before a decision is made.

The above definitions provide a broad indication of the different concepts of the EIA. The EIA is normally considered to be a technical exercise. The main objective is to provide the decision makers and the public with an account of the implications of proposed courses of action before decisions are taken.

The results of the assessment are collected into a document known as an environmental impact statement (EIS). The EIS includes benefits and adverse impacts considered relevant to the project and to plans and policies under consideration. The completed EIS is one component of information upon which the decision maker take the his actions. Other factors such as unemployment, energy requirements or national policies may also influence the final outcome.

The EIA should be implemented at the project planning and design stage to improve the decision making process. It must be an integral component in the design of a project rather than something added to the technical development of a project. This means a continuous feedback between EIA findings, project design and locations.

The most important consideration of potential effects of the various air pollutants on:

- health and well being of humans
- impact on fresh water resources
- flora and fauna
- materials (building stock and monuments).

The time scale is of great importance. Short term acute toxicity represented by very high concentrations over short periods of time, often linked to accidental releases or conditions leading to air pollution episodes, act differently from long term chronic exposure. The latter type is often connected to deposition, uptake and intake over time. Different pollutants have to be considered on different scales in time and space

8.2 Air Pollution Impact

8.2.1 Air pollution and human health

The assessment of the air quality in the European Community is presently being linked to the air pollution levels and to the size of populations and ecosystems exposed to these levels. To protect the health, the concentrations of selected harmful air pollutants should be limited and related to given ambient air quality standards.

Several investigations have been performed by international scientific groups to estimate the impact to human health from various air pollutants. The exposure of humans to air pollutants is usually a mixture of different air pollution compounds originating from different sources. It has therefore been difficult to establish reliable dose /response relationships from actual field data.

Air quality standards and guidelines have been established based upon air pollution impact also to the human health and well-being. The best available background material for evaluation of health impacts is the US- EPA criteria documents and the air quality guidelines for Europe (WHO, 1987 and 1995). The air quality guidelines is formulated to ensure that populations exposed to concentrations lower than the guideline values should not inflict harmful effects. In cases where the guideline for a pollutant is exceeded, the probability of harmful effects will increase.

The WHO guideline values for selected pollutants are presented in ch. 3 on air quality indicators. There are also several national standards or proposed guidelines available related to human health.

As one example of the results presented from air pollution and health studies have been obtained from a study on the health impact of traffic air pollution in Norway. From more than one thousand persons followed through diaries and questionnaires the statistical analyses indicate that various symptoms of health and well being were correlated to exposure to traffic pollution equivalent to NO_2 levels even less than 200 $\mu g/m^3$ as one hour averages. Headaches, coughing, eye irritations, throat problems and depression were some of the symptoms asked for.

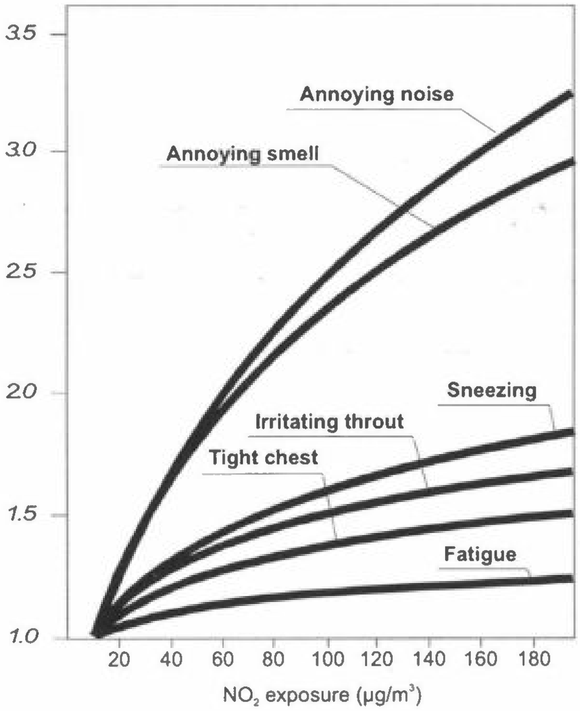


Figure 75: Self reported health symptoms versus NO_2 exposure

The basic information used in comparing alternative strategies in air pollution planning is the performance of exposure estimates.

8.2.2 Exposure estimates

A simplified method for performing exposure estimates was developed for planning purposes in Oslo. The contribution of air pollution from vehicular traffic, home heating and industry to the population exposure was calculated based upon data for emission, dispersion and population distributions.

The calculations were carried out in a 1 km^2-grid with specific calculations for roads with high traffic and for large point sources. Based on data for; a) pollution advection into each km^2, b) local contribution within each km^2 and c) concentrations close to streets with high traffic, estimates were made of the cumulative spatial distribution of air pollution within each km^2. These concentrations were then used together with the population distribution to estimate a rough exposure curve for each km^2. When added for all grids the method became a fairly robust method for obtaining a complete picture of the population exposure to air pollutants in Oslo. The curves were presented as the number of people living within areas of concentrations exceeding given levels.

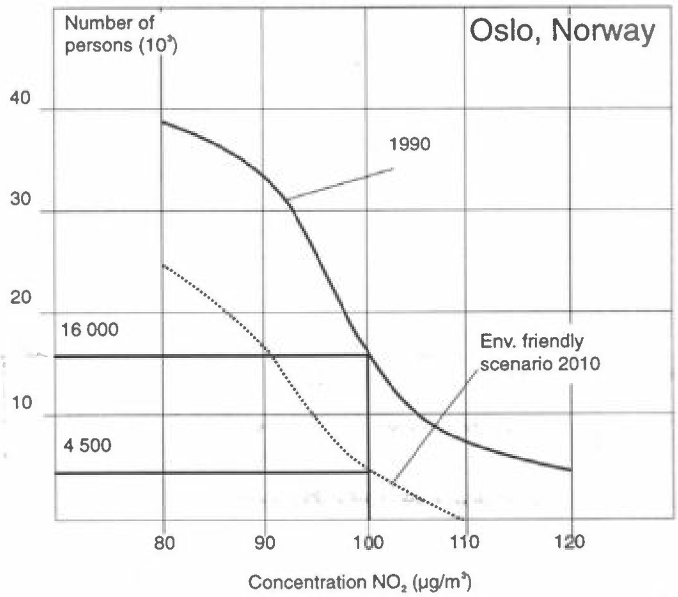


Figure 76: Estimated NO_2 exposure to the population of Oslo, Norway

The Norwegian State Pollution Control Authority initiated an abatement strategy study in Oslo to evaluate the benefit of improved air quality versus the cost of different emission reductions. A total of 38 measures were evaluated with respect to improvement of air quality in Oslo year 2000. The basic alternative was no change in activity except for introduction of catalytic converters installed in new gasoline cars from 1988.

The maximum concentration levels included in this study was representative for a cold winter day in Oslo when the emissions are captured beneath an inversion layer which cause high impact of air pollution. The air quality guideline values used were; 50 $\mu g/m^3$ for black smoke and 100 $\mu g/m^3$ for SO_2 and NO_2.

The basic alternative for year 2000, with no emission reduced activities included except for catalytic converters for cars, gave that about 184 000, 150 000 and 12 000 persons were exposed for concentrations above air quality guidelines for SO_2, soot and NO_2, respectively.

To perform a cost/benefit priority of the 38 different measures, the evaluation of cost of each measure had to be carried out.

The number of people living in each km^2 combined with the concentration distributions are used to summarize the population exposure to 24 hour mean episodic concentration values.

Population exposure curves for SO_2, NO_2, CO and particulate matter were used to evaluate future air quality as a result of alternative emission situations.

8.2.3 Air pollution and flora and fauna

Studies of plant damage and air pollution impact on plant growth have been performed for several individual air pollutants and for air pollution mixtures. In the discussion of specific air quality indicators considerations of recent scientific results on plant damage have been considered.

Also the consideration of critical loads should be taken into account. The **critical load** values is defined as a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.

The critical level for a given area depends strongly upon geology, vegetation, climatology, and soil properties. It might thus be difficult to generalize. It is possible to extrapolate maps of critical levels and loads for the fresh water system. These maps show the deposition of acid air pollutants that the water system is able to handle before the water biotop is damaged. It is also possible to extrapolate maps on uptake of pollutants in plants and by surfaces. This requires a vegetation map and a model for uptake by plants.

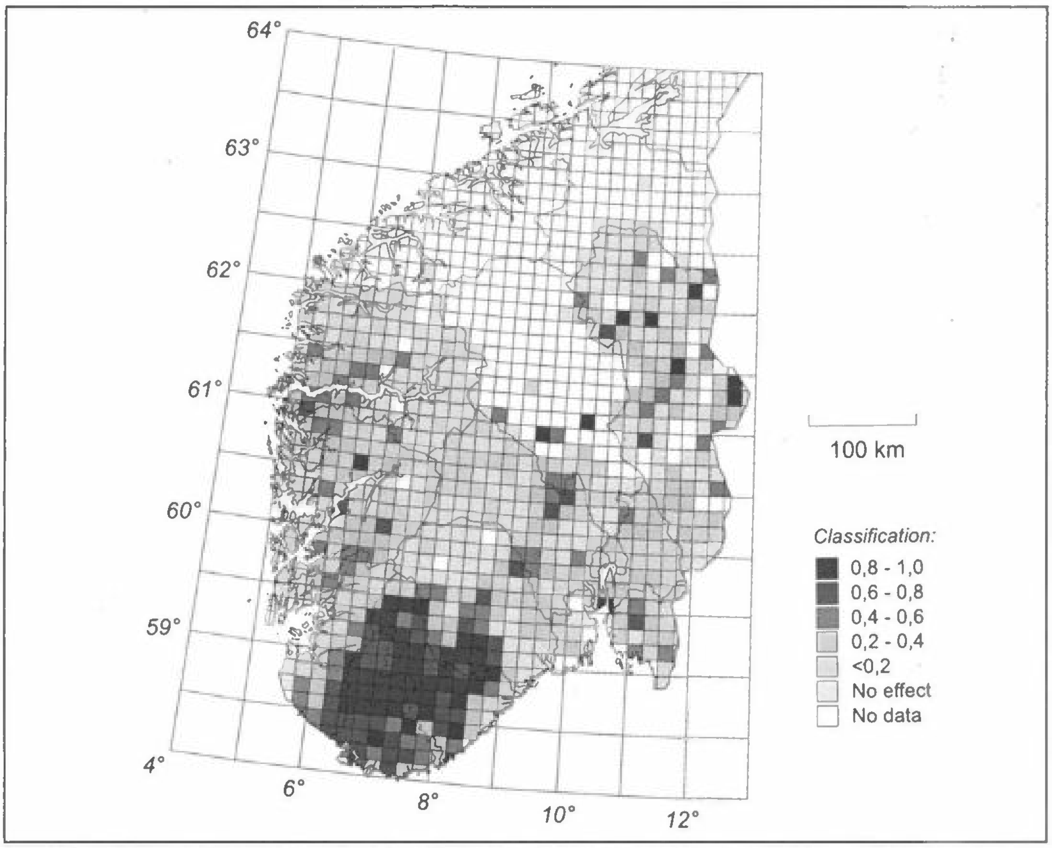


Figure 77: Exceedance of critical loads for freshwater systems in Norway

An important air pollution indicator when discussing plant damage is ozone., The phytotoxic effects of ozone have been extensively studied. In certain sensitive species, ozone may cause direct damage in the form of necrotic spots. Tobacco (especially the sensitive cultivator Bell W3), spinach, beans, and clover are examples of plants that will show characteristic tissue damage symptoms if exposed to ozone concentrations above certain levels.

Ozone also causes invisible damage, because it interferes with the photosynthesis assimilation of carbon dioxide in the stomata. This effect has also been systematically studied, both in laboratory (e.g. Forberg et al., 1989) and in so called open-top chambers, where plants can be grown and exposed to different concentration levels of ozone under field conditions (Heck et al., 1982). These latter experiments have shown that the crop yield losses due to ozone exposure are considerable in both Europe and in North America. Closer examination of these data have shown that the growth reductions are related to the Accumulated exposure of Ozone above a certain Threshold of 40 ppb (AOT40)(Fuhrer and Achermann,1994).

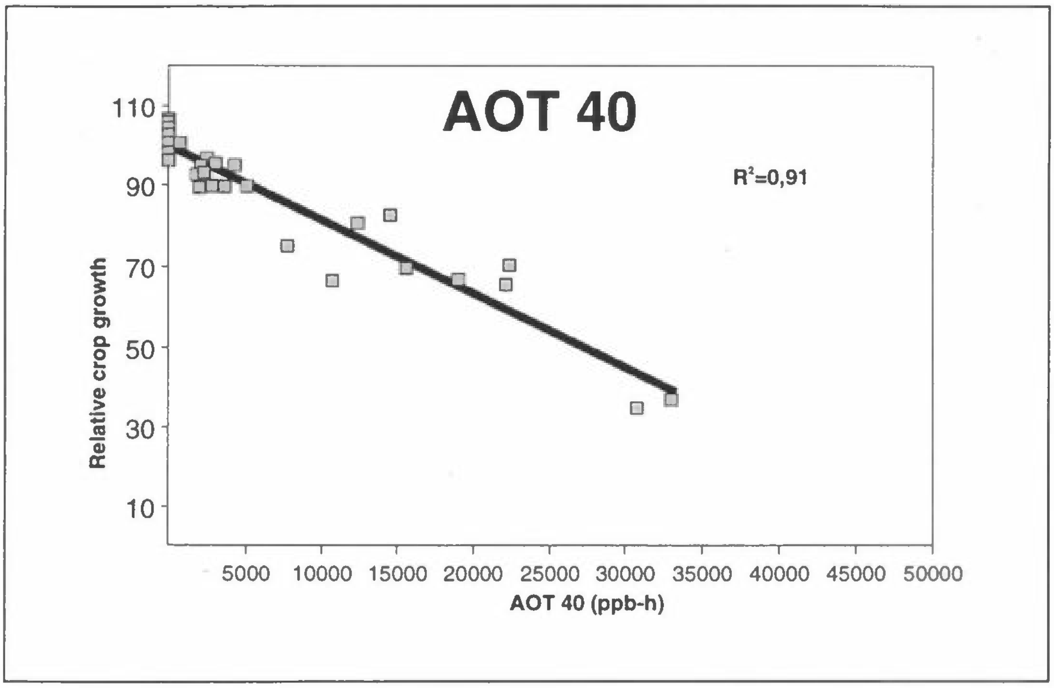


Figure 78: Crop growth reductions as a function of ozone exposure expressed as ozone exceedances of 40 ppb (80 μg/m³) (AOT40).

The workshop further recommend that the critical level of protection of agricultural crops and forests should be set at 5000 ppb/hours and 10 000 ppb/hours, respectively, The AOT40 values for the crops to be calculated for a 3-month period during daylight hours only, and the AOT40 value for forests for a 6-month period. These critical levels have been set according to laboratory- and field experiments and a reduction on plant growth of 10%.

The impact on animals is often linked to the food chain processes. Effects of specific toxic substances, especially some toxic heavy metals, long lived chlorinated compounds, organic compounds have however, been included in the list of air quality indicators.

8.2.4 Air quality and atmospheric corrosion

The concern for our cultural heritage and for the general life time of buildings and constructions have increased during the last few years. Considerations for this part of our environment and for the cost of restoration and rebuilding, should be built into the air quality levels when considering air pollution indicators.

As for human health the impact is usually a result of mixtures of compounds included air pollution, climate, weathering, wind, humidity, temperature, erosion, freezing, etc.

Dose response relationships have been established for a few specific air pollutants. For SO_2 these data have been used in cost/ benefit analyses for sulphur- reduction measures linked to the use of fuel oil in Europe.

For a small country like Norway estimates have shown that the annual maintenance costs on building materials caused by air pollution is more than 300 mill. NOK (60 mill US $). Table 15 indicate the savings potential related to a decrease in SO_2 air pollution levels in Norway.

Table 15: Atmospheric corrosion costs on the Norwegian building stock.

	Costs		Savings
	1985	1984	1985-1994
Maintenance costs	496	198	298
Allocation costs	233	93	140
Total	728	291	438

8.3 Consequence analysis

All major man made changes will have positive and negative effects on the environment. Before these changes are made it is important to get an overview of the consequences of the change. There are different ways of getting this overview. The method described here is the consequence analysis.

The objective of the consequence analysis is to bring forward information on environmental issues and the impact on a specific project to the environment.

Phases:

1. Initial screening of problems
2. Preliminary analysis
3. Full analysis

The two last steps is the contents of the consequence analysis. The amount of work put into the different stages and how far in the analysis it is necessary to go can be evaluated, but the environmental consequence analysis shall contain direct and indirect consequences for :

- natural environment
- natural resources
- future management of natural resources
- man made environments
- human health

A check list of necessary steps can be made, and NORAD and the Norwegian authorities have presented typical check lists for consequence analysis.

An initial screening has the objective of helping project desk officers and planners to assess a project in relation to environmental impacts. The initial assessment shall provide a survey of environmental impacts likely to ensue if a project is implemented. Usually an initial assessment will be based on easily accessible information, former research, the local populations views etc..

Only potential environmental impacts, direct and indirect, are identified in the initial assessment. Estimates are not assumed to be substantiated by special accounts or registrations, but rather come under full assessment .

The consequence analysis must take into consideration the following points

- technical description of the project
- the situation in the area today
- consequences for the society
- consequences for the environment and natural resources
  - emissions to air
  - emissions to water
  - noise
  - waste management
  - impact on the landscape

The contents of the consequence analysis must be made available to the public. It is also necessary the government put forward guide lines on how to make a consequence analysis and the issues that have to be investigated before a permission of releases to air will be given from the government.

8.4 Optimal abatement strategy planning

The process of developing an Air Quality Management Strategy (AQMS), for an urban area includes many steps. The most important of these are listed on the next page:

* - identifying sources		
* - quantifying sources	emission inventory	
* - monitoring of air pollution		Assessment
* - assessing the exposure (impact) situation		
* - identifying source - exposure relations		
* - estimating the relative importance of the exposure of various AP sources		
* - assessing environmental damage		
* - investigating control (abatement) options		
* - performing cost-benefit or cost-effectiveness analysis		Control
* - developing a control strategy and an investment plan		
* - developing institutions/regulations/enforcement		
* -establishing an Air Quality Information System (AQIS)		Surveillance

As shown above, the AQMS consists of two main components, which are assessment and control. In parallel with the AQMS development, and to facilitate checking the effectiveness of the air pollution control actions, a third component is necessary, which is surveillance.

The process of attaining acceptable urban air quality is definitely long term, and it is dynamic. The urban area develops, and population, sources and technology change. Throughout this process, it is very important to have an operating Information System of Air Quality (AQIS), in order to

- keep the authorities and the public well informed about the short-term and long-term air quality development,
- control the results of abatement measures, and thereby,
- provide feed-back information to the abatement strategy process.

The basic concept for an Air Quality Management Strategy contains the following main components:

- Air Quality Assessment
- Environmental Damage Assessment
- Abatement Options Assessment
- Cost Benefit Analysis or Cost Effectiveness Analysis
- Abatement Measures
- Optimum Control Strategy

The Air Quality Assessment, Environmental Damage Assessment and Abatement Options Assessment provide input to the Cost Benefit or Cost Effectiveness Analysis, which is also based on established Air Quality Objectives (i.e. guidelines, standards) and Economic Objectives (i.e. reduction of damage costs). The final result of this analysis is Optimum Control Strategy.

The establishment and follow-up of the AQMS require that an integrated system for continued air quality management is established/completed in Jakarta. A system for air quality management requires continuing activities on the urban scale in the following fields:

- Inventorying of air pollution activities and emissions
- Monitoring of air pollution and dispersion parameters
- Calculation of air pollution concentrations, by dispersion models
- Inventorying of population, materials and urban development
- Calculation of the effect of abatement/control measures
- Establishing/improving air pollution regulations.

These activities, and the institutions necessary to carry them out, constitutes the System for Air Quality Management that is a prerequisite for establishing the Strategy for Air Quality Management (AQMS).

In megacities in developing countries, a build-up period of several years should be considered to establish a complete system for Air Quality Management.

During this development period, intermediate strategies for controlling the present air pollution problems and their development must be worked out. These intermediate strategies must be based on existing data, and additional information and data that can be acquired over a relatively short time (~1 year). This data base will not be complete, but the intermediate strategies will represent the optimum control strategy, given the data available.

8.5 Cost/benefit analysis (example Manila)

8.5.1 Action plan

Through the work carried out in the local working groups, a large number of proposed actions and measures has been listed, and categorized within the following categories (Larssen et al., 1995):

- Improved fuel quality.
- Technology improvements.
- Fuel switching.
- Traffic management.
- Transport demand management.

Each of the proposed actions were described regarding its effect (benefit), costs, policy instruments, time-frame of instigation, and institutions responsible.

A selection of "obvious" technical measures for possible short-term introduction was made, and cost-benefit analysis carried out for each measure separately.

The Table below gives a summary of the cost-benefit analysis. For all of the selected measures except cleaner fuels in power plants, the calculated benefits are very substantial, in the tens of millions of USD annually, and the benefits are, as a rule, much higher than the estimated costs.

Table 16: Benefits and costs of selected abatement measures, annual figures.

Abatement Measure	Benefits		Cost of measure mill USD	Time frame, effect of measure
	Avoided effects	Reduced costs mill USD		
Address gross polluters (Anti Smoke Belching Campaign)	160 deaths 4 mill RSD	16-20	0.08	Short-term
Improving diesel quality, vehicles	94 deaths 2.5 mill RSD	10-12	10	2-5 years
Inspection/maintenance, vehicles	310 deaths 8 mill RSD	30-40	5.5	2-5 years
Clean vehicle standards	895 deaths 24 mill RSD	94-116	10-20	5-10 years

8.5.2 Future air quality for some abatement scenarios

In order to be able to draw overall conclusions regarding the possibility to improve the air pollution situation in Metro Manila, two combined future scenarios have been defined:

- "Common environmental technology scenario", based on a comprehensive strategy to address "smoking" diesel fuelled vehicles including introduction of clean diesel fuel; introduction of unleaded fuel and clean vehicle emissions standards; further reduction of sulphur contents in fuel oils.

- "A fuel shift scenario", involving gradual shift to LNG for energy production, and introduction of LPG (and CNG) as automotive fuel for buses and trucks particularly.

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ABSTRACT
The elements of a modern air quality monitoring system has been presented and discussed. The monitoring programme included sensors and instruments, data transfer, quality assurance, modelling, data presentation and data application are all part of the system.

NORWEGIAN TITLE Integrert måle-, informasjons- og presentasjonssystem for luftkvalitet

KEYWORDS

Air quality	Monitoring system	Data applications

ABSTRACT (in Norwegian)

Et moderne system for luftkvalitet inneholder sensorer, instrumenter, dataloggere og dataoverføringssystem, inkludert kvalitetskontroll, modellberegningsverktøy og grafiske presentasjonspakker. Det integrerte systemet, samt eksempler på bruk av data er presentert i rapporten.

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