Data collection, processing and evaluation system

Pollution and air quality
Atmospheric deposition
Greenhouse gases

Czech
Hydrometeorological
Institute

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Introduction

This document presents a methodological material that describes the system of work in the Czech Hydrometeorological Institute (CHMI) for data collection and processing, divided according to professional subject matters. Furthermore, the current methodology used to assess air quality is also described.

The document describes methodological procedures for collecting data on air pollution and air quality, atmospheric deposition, greenhouse gases, emissions, and other phenomena affecting our ambient air and climate which are areas covered by the CHMI Air Quality Division. There is also a description of the presentation and reporting of data for each area.

The document is an accompanying material to the CHMI tabular and graphic yearbook. The graphic yearbook "Air Pollution in the CR in 2019" (CHMI 2020a), together with the electronically published data yearbook "Summary Tabular Survey" (CHMI 2020b), is a comprehensive overview of information on air quality in the Czech Rebublic in a given year. The data yearbook presents verified measured air pollution data and data on the chemical composition of atmospheric precipitation from individual localities including aggregated data, the graphic yearbook provides commented summary information in overview maps, graphs and tables.
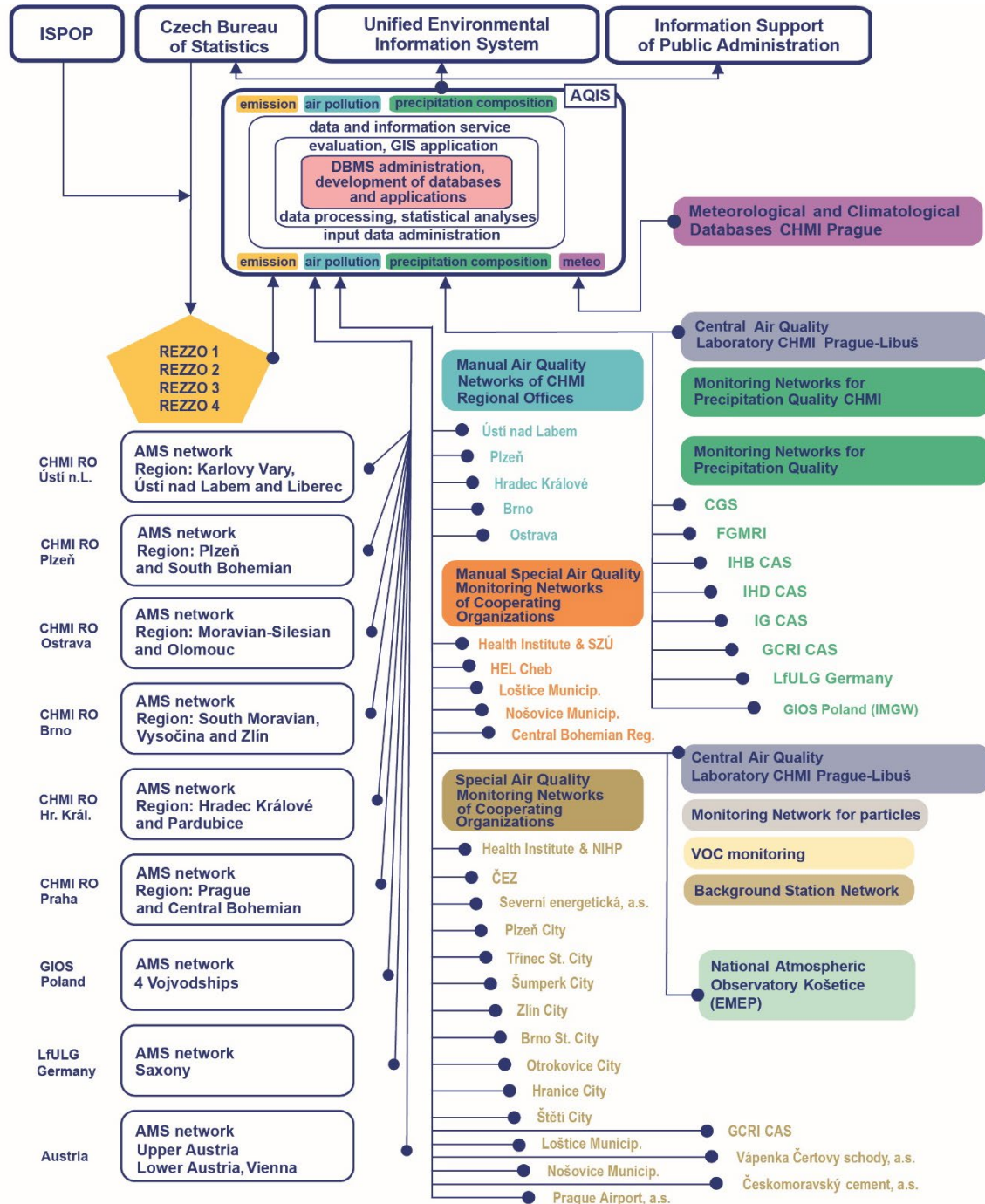
1. Data collection and processing

The "Air Quality Information System" Department (hereinafter referred to as the "AQIS Department") is responsible for the collection, processing and archiving of data in the CHMI. The AQIS Department also cooperates with individual professional sections to fulfil these activities. The AQIS database (hereinafter referred to as "AQIS") is operated under the Oracle database system.

The AQIS Department was established in 1990. It was created by transforming the former "Air Pollution Information System" (IIS), which was formerly part of the "Meteofond" and "Air Quality" Department which dealt with emissions, transmissions (transport and dispersion) and air quality.

AQIS is operated on the basis of the Air Protection Act, currently Act No. 201/2012 Coll., as amended. The operation of the system is entrusted by the Ministry of the Environment (MoE) to the Czech Hydrometeorological Institute (CHMI).

AQIS is being continuously developed and operated using current information technologies as an integrated system for countrywide comprehensive assessment of the state and development of air pollution; it encompasses collection, archiving and processing of data from automated and manual monitoring networks of the CR (air pollution database and database of chemical composition of precipitation) as well as storage and processing of data on emissions and sources of air pollution (emission database). In recent years, ISKO has also included the National Inventory System for Greenhouse Gases. With the air pollution data, the accompanying meteorological data are also stored in the air pollution database, which are collected at a large part of the CHMI automated air pollution stations and are used for the evaluation of air pollution-meteorological relations (Fig. 1).

ISPOP | **Czech Bureau of Statistics** | **Unified Environmental Information System** | **Information Support of Public Administration**

AQIS
emission · air pollution · precipitation composition

data and information service
evaluation, GIS application
DBMS administration, development of databases and applications
data processing, statistical analyses
input data administration

emission · air pollution · precipitation composition · meteo

Meteorological and Climatological Databases CHMI Prague

REZZO 1 REZZO 2 REZZO 3 REZZO 4

CHMI RO Ústí n.L. — AMS network Region: Karlovy Vary, Ústí nad Labem and Liberec

CHMI RO Plzeň — AMS network Region: Plzeň and South Bohemian

CHMI RO Ostrava — AMS network Region: Moravian-Silesian and Olomouc

CHMI RO Brno — AMS network Region: South Moravian, Vysočina and Zlín

CHMI RO Hr. Král. — AMS network Region: Hradec Králové and Pardubice

CHMI RO Praha — AMS network Region: Prague and Central Bohemian

GIOS Poland — AMS network 4 Vojvodships

LfULG Germany — AMS network Saxony

Austria — AMS network Upper Austria Lower Austria, Vienna

Manual Air Quality Networks of CHMI Regional Offices
- Ústí nad Labem
- Plzeň
- Hradec Králové
- Brno
- Ostrava

Manual Special Air Quality Monitoring Networks of Cooperating Organizations
- Health Institute & SZÚ
- HEL Cheb
- Loštice Municip.
- Nošovice Municip.
- Central Bohemian Reg.

Special Air Quality Monitoring Networks of Cooperating Organizations
- Health Institute & NIHP
- ČEZ
- Severní energetická, a.s.
- Plzeň City
- Třinec St. City
- Šumperk City
- Zlín City
- Brno St. City
- Otrokovice City
- Hranice City
- Štětí City
- Loštice Municip.
- Nošovice Municip.
- Prague Airport, a.s.

Central Air Quality Laboratory CHMI Prague-Libuš

Monitoring Networks for Precipitation Quality CHMI

Monitoring Networks for Precipitation Quality
- CGS
- FGMRI
- IHB CAS
- IHD CAS
- IG CAS
- GCRI CAS
- LfULG Germany
- GIOS Poland (IMGW)

Central Air Quality Laboratory CHMI Prague-Libuš

Monitoring Network for particles

VOC monitoring

Background Station Network

National Atmospheric Observatory Košetice (EMEP)

- GCRI CAS
- Vápenka Čertovy schody, a.s.
- Českomoravský cement, a.s.

Explanations:

AQIS	Air Quality Information System
DBMS	Database Management System
GIS	Geographic Information System
CHMI RO	CHMI Regional Office
NIPH	National Institute of Public Health
FGMRI	Forestry and Game Management Research Institute
Hel Cheb	Hygienic and ecological laboratories Cheb
AMS	Automated Monitoring Station
ISPOP	Integrated System of Compliance with Reporting Duty in Environmental Areas

REZZO	Register of emissions and stationary sources
CGS	Czech Geological Survey
IHB CAS	Institute of Hydrobiology of the Czech Academy of Sciences
IHD CAS	Institute of Hydrodynamics of the Czech Academy of Sciences
IG CAS	Institute of Geology of the Czech Academy of Sciences
ICPE CAS	Institute of Chemical Process Fundamentals of the Cz. Acad. of Sc.
GCRI CAS	Global Change Research Institute of the Cz. Acad. of Sc.
LfULG	Landesamt für Umwelt, Landwirtschaft und Geologie Dresden, FRG
GIOS	Główny Inspektorat Ochrony Środowiska, Poland
IMGW	Institute of Meteorology and Water Management, Wroclaw, Poland

Fig. 1 Ties of the AQIS to data sources and co-operating systems, 2019

1.1 Air pollution – emissions

The term air pollution (emissions) encompasses a range of processes that lead to release of pollutants into the air. Air pollution sources are of natural or anthropogenic origin and the borderline between these two types is not always unambiguous. Natural sources include volcanic activity, forest fires, substances produced by plants, etc. Anthropogenic sources involve human activities. Primary air pollution is understood as a release of pollutants into the air directly from their sources, while secondary pollutants are formed as a result of physical-chemical reactions in the atmosphere (ozone, secondary aerosol particles, most NO_2 etc.). A specific process, closely related to primary pollution, is the swirling of fine and coarse dust particles deposited on the earth's surface, which occurs during the movement of road vehicles and agricultural machinery, or, for example, in stronger winds. This process, called resuspension, involves dust particles, but it also re-introduces substances into the air that are bound to the dust particles, such as heavy metals and POPs.

The CHMI evaluates the level of air pollution under authorisation by the Ministry of the Environment for primary pollutants of anthropogenic origin. The basic background material for this evaluation consists of the "emission inventory" which combines direct collection of data reported by the operators of sources with model calculations of data reported by the operators of sources or determined in the context of statistical studies performed primarily by the Czech Statistical Office. The resulting emission inventories are presented in a form of emission balances in sectoral and territorial classifications.[1]

There is a wide range of pollutants that sources release into the air. Regular emission inventory related to the concept of air pollution is performed for dust particles (SPM, PM_{10} and $PM_{2.5}$ fractions), acidifying gases (SO_2 and NO_X), carbon monoxide, volatile organic compounds and ammonia. Other monitored pollutants are selected heavy metals, some of which also have set air quality limits (arsenic, cadmium, nickel and lead), polycyclic aromatic hydrocarbons (the monitored pollutant in the air is benzo[a]pyrene), and also e.g. PCDD/F and PCBs. Emission inventories are also performed for other substances, e.g. benzene, NO_2, carbon particles, etc.

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1 The methodology and results of emission inventories are available at:
http://portal.chmi.cz/files/portal/docs/uoco/oez/emisnibilance_CZ.html

1.1.1 Collection of emission data

From the viewpoint of the means of monitoring emissions, air pollution sources are divided into individually monitored sources and collectively monitored sources. In connection with the categorization of sources according to Annex No. 2 of the Air Protection Act 201/2012 Coll. and the method of reporting the data of the summary operational records according to Annex No. 11 to Decree No. 415/2012 Coll. the following breakdown of resources is used (Tab. 1).

Tab. 1 Classification of air pollution sources according to the method of emission monitoring

Type of sources	Specified stationary sources	Unspecified stationary sources	Mobile sources
Category	REZZO 1, REZZO 2	REZZO 3	REZZO 4
Included	Stationary combustion plants for combustion of fuels with a total nominal heat consumption higher than 0.3 MW, waste incinerators, other sources (technological combustion processes, industrial production etc.).	Stationary combustion plants for combustion of fuels with a total nominal heat consumption up to 0.3 MW. Unnamed stationary technological sources and other activities producing emissions (see below).	Road, railway, water and air transport of persons and freight, for road transport also tyre and brake wear, road abrasion** and evaporation from fuel systems of vehicles using petrol, operation of off-road vehicles and machines used in maintenance of green spaces in parks and forests etc.
Data origin	Reported emission data except for the simple reports* pursuant to Annex No. 11 to the Decree No. 415/2012 Coll.	Calculated emissions from activity data, obtained e.g. from the Census, production and energy statistical surveys, road traffic census and the register of vehicles etc., and emission factors.	
Recording method	Individually monitored sources • REZZO 1 – reported emissions • REZZO 2 – emissions calculated from the reported data on fuel consumption and emission factors.	Sources monitored collectively.	Sources monitored collectively.

*   operator reports only the consumption of fuels and distribution of petrol

**   resuspension of dust particles from the road surface is not included in the inventory

The sources listed in Annex No. 2 of the Act No. 201/2012 on the air protection are monitored individually. Pursuant to Article 17(3)(c), the operators of these sources are obliged to keep operating records of permanent and variable data on stationary sources, describing the source and its operation, and also data on inputs and outputs from these sources. They are also obliged to annually report information on the summary operating records (SPE) through the Integrated system of fulfilling reporting obligations (ISPOP) introduced by Act No. 25/2008 Coll., on the integrated register of environmental pollution and the integrated system of compliance with environmental reporting obligations and on the amendment of certain acts. ISPOP data are then collected in the REZZO 1 and REZZO 2 databases. An exception holds for movable stationary sources (especially part of sources included under code 5.11. of Annex No. 2 to the Act on Air Protection – Operation of recycling lines for building materials), for which the place of their operation may change during the year. Emissions from these sources are reported collectively for operation within the entire region and are therefore

recorded under the REZZO 3 category. Collection of data for the previous year takes place from January to the end of March. Reported data are available at the beginning of April and verification and processing of the submitted reports then take place in the following months. The processes introduced by the AQIS emission data management operating rules also include extensive inspections of reported data, calculations of emissions not ascertained by the notifier, completion of unreported parameters and correction of erroneous data.[2]

Collectively monitored sources incorporated in REZZO 3 include emissions from unspecified combustion sources (i.e. of a nominal heat consumption up to 0.3 MW), construction and agricultural activities, surface use of organic solvents, filling stations, coal mining, fires of cars and buildings, waste and waste-water treatment, use of fireworks, cigarettes, shoe cleaners, etc. Emissions from these sources are determined using data collected by national statistical surveys and emission factors. The group of unspecified combustion sources includes the sector of heating of households, highly significant in terms of emissions, for which a specific methodology for determination of emissions is used. Other sectors encompass services, commerce, authority offices, educational and medical institutions, and also the army sector (neither SPE data nor army sources included in Annex 2 of the Air Protection Act are included in reported data since 2017).

The data used for the evaluation of emissions from collectively monitored combustion sources include, in particular, the outputs of the 2011 SLDB Census, regularly updated by data on housing construction provided by the Czech Statistical Office. Furthermore, there are climatic data, data on the calorific value and quality of fuels supplied to households and the results of extensive measurements performed to determine the emission factors of all major groups of combustion sources, classified by the type of combustion equipment and type of fuel. An estimate of a share of a particular type of household combustion equipment on fuel consumption has been based on results of the ENERGO 2015 statistical survey, SLDB and statistics of sales of boilers, fireplaces and heaters.

For most other collectively monitored stationary sources, methodologies are used, for which summary statistical data are regularly collected, broken down by individual regions, or countrywide only. These include livestock statistics, production of selected products and fuel extraction, aggregate data for construction, fires, sales of selected commodities (fertilizers, organic solvent products, fireworks, cigarettes), data on landfills or wastewater treatment plants and more. GIS information is also used for some methodologies.

Data from mobile sources are also monitored collectively (REZZO 4) and include emissions from road (including VOC emissions from vehicle fuel system petrol evaporation and emissions from brake, tyre and road abrasion), rail, water and air transport, and operation of off-road machinery and mechanisms (agricultural, forest and construction machinery, military vehicles, greenery maintenance, etc.). An inventory of emissions from mobile sources is maintained by CDV Brno, p. r. i. and VÚZT Praha, p. r. i. Emissions from road traffic are estimated using the international COPERT 5 methodology. Transport statistics, data on fuel sales, data on a composition of vehicle fleet according to the Register of Vehicles of the CR and data on annual mileage of vehicles according to the output of registers of the Technical Inspection Stations are used to determine a share of a particular group of vehicles on fuel consumption. Data from the Register of Vehicles and from the Technical Inspection Stations are also used for model evaluation of emissions of agricultural machinery (especially tractors). For other groups of mobile sources, fuel sales statistics and transport statistics information (rail, water and air transport) are used. In accordance with legislative provisions, some emissions from transport are not added to the total assessed emissions. In the CR, this applies to the air transport sector which only includes emissions from the landing and take-off cycle. This means that emissions from the flight phase (approximately from 1 km of flight altitude) and emissions from aircraft flying over the territory of the CR are excluded.

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2 For the mechanisms of summary operating records (SPE), see:
  http://portal.chmi.cz/files/portal/docs/uoco/oez/emise/evidence/aktual/spe_uvod_cz.html

The methodological development and annual countrywide processing and management of the emission database archive is provided by the CHMI in cooperation with external suppliers (CDV Brno, p. r. i., VÚZT Prague, p. r. i., SVÚOM Prague). The scheme of data processing of individually and collectively monitored sources is shown in Fig. 2. The time series, starting around 1984, incorporates the reported annual emission data and accompanying technical data of the most important group of operator facilities (formerly especially large and large sources referred to as REZZO 1) within the AQIS emission data. Since the 1990s, the database also includes data on sources classified by previous legislation as so-called medium sources of air pollution (formerly REZZO 2 sources). Data from collectively monitored sources are archived in the form of expert reports with accompanying tabular data.
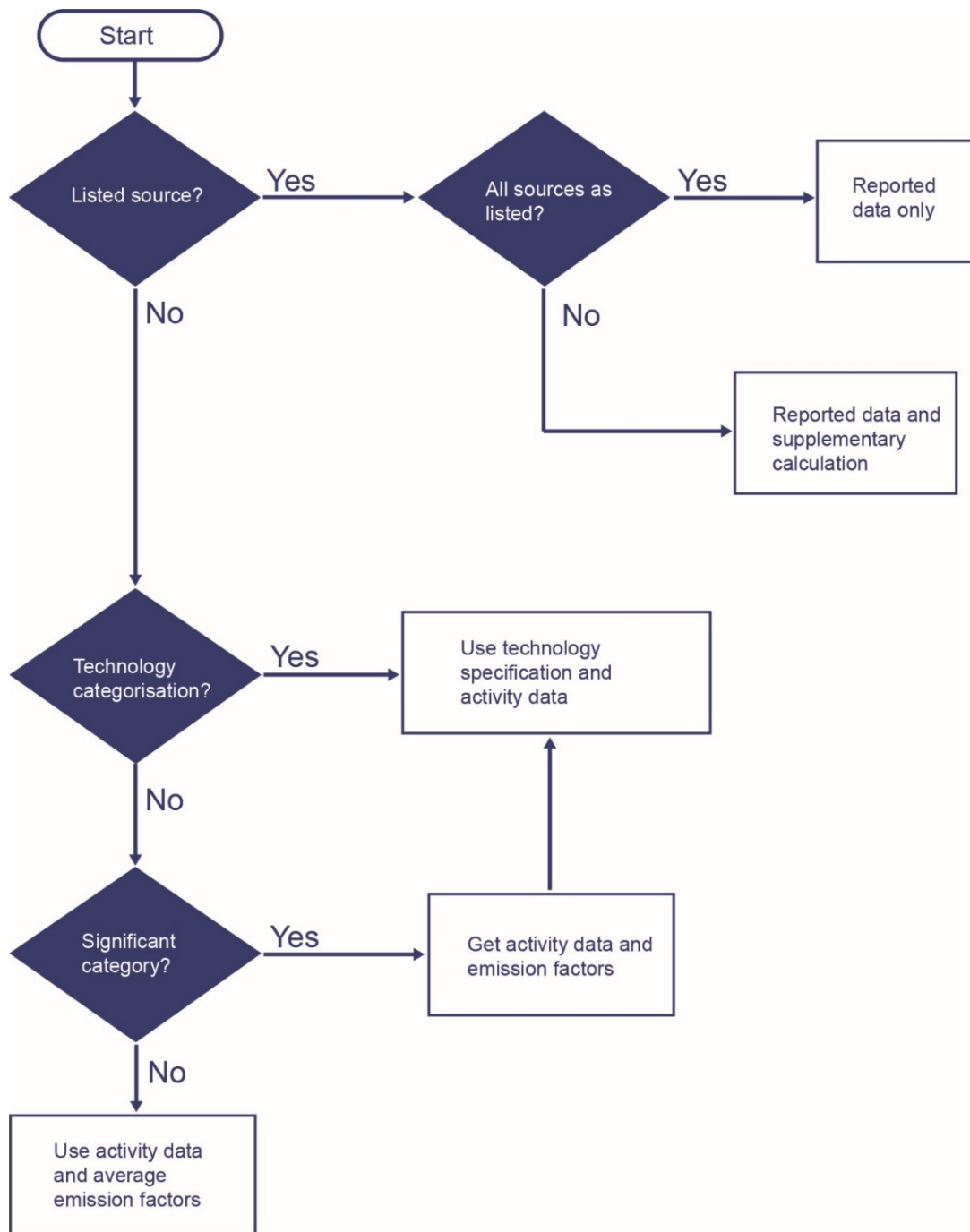
Fig. 2 The scheme of data processing of individually and collectively monitored sources

1.1.2 Processing and presentation of emission data

The processing of REZZO 1 and 2 emission data takes place partly automatically within the emission part of the AQIS database and mainly includes the upload of reporting files, lists of facilities and operators, recording of system information and automated calculation of necessary parameters and emissions. It is then possible to export on-line data of specific reports, control map previews, multi-annual overviews for tracing trends and other outputs, necessary especially for the control of reported data. Emissions of pollutants which operators are not obliged to observe, are determined by calculation for the needs of international reporting and modelling of air quality in the emission part of the AQIS database on the basis of reported activity data and emission factors. Emission factors for stationary combustion sources are differentiated according to the type of furnace and heat output, the initiation data is fuel consumption. For other sources, emission factors depend on the type of technological process, the type and quantity of product and the way in which emissions are reduced. To determine the emissions of PM_{10} and $PM_{2.5}$, the percentages of the given PM fraction in the total emissions of SPM are used. If the source is equipped with a separator to reduce SPM emissions, the share of the SPM fraction depends on the separation principle of this device. For combustion sources without a separator, the fractions are determined according to the type of fuel, for other sources the method of formation of SPM is a key factor (Hnilicová 2012).

REZZO 3 data processing takes place in the MS Excel spreadsheet using the manual input of the necessary fresh data, particularly statistical data. REZZO 4 data processing takes place at external suppliers by similar means (specialized applications and MS Excel) and the outputs are delivered to the CHMI directly in the format required for emission inventories.

The standard outputs of emission inventories are countrywide and regional balances, made mainly for basic pollutants. For the needs of model evaluation of air quality, detailed lists for pollutants with established air pollution limits are created. These data are prepared in a form for either point emissions (chimneys, exhausts, fugitive leaks) or emissions assigned to a defined area in connection with possibilities of their attribution (basic settlement units, municipalities, regions).

The so-called sectoral breakdown of sources given by the Nomenclature for Reporting Codes (NFR) is used for the international reporting of aggregated emission data. The main groups of sources are combustion sources including transport (NFR 1), technological sources without combustion, so-called processes emissions (NFR 2), sources using solvents (NFR 2D), agricultural activities including livestock breeding (NFR 3B) and waste management. (NFR 5). The method of conducting the emission inventory is described in detail in a document (CHMI 2020c) submitted annually as part of emission data reported in accordance with the requirements for international reporting (European Parliament and Council Directive (EU) 2016/2284 and CLRTAP Convention). The Report on the implementation of emission inventories (IIR) presents the results of the emission inventory since 1990. Emissions can be continuously updated, for example on the basis of recommendations in the detailed inventory review (most recently in 2015) or specific evaluations carried out annually by an international team of experts under responsibility of the European Commission.

In addition to the already mentioned emission balances, the CHMI portal also presents data on individual emission sources in the REZZO 1 Source list and specific information on thermal recovery and waste incineration (e.g. List of waste incinerators and waste co-incineration plants and Registry of waste incineration and co-incineration permits).

1.2 Air quality

Air quality is characterised by concentration of harmful substances in the ambient air. The pollutant contained in the air comes into contact with the recipient (human, plant, animal, material) and has a negative effect on it. Pollution of the air occurs after the physical-chemical conversion of emissions released to the air. Air pollution concentrations in the CR are most often reported in $\mu g \cdot m^{-3}$ or $ng \cdot m^{-3}$, abroad, we often meet also with an indication of air pollution concentrations in units of ppb or ppm.

A pollutant is any substance which, by its presence in the air, has or may have harmful effects on human health or the environment or presents a trouble by odor (Act No. 201/2012 Coll., on air protection). Emission concentration is measured directly at its source, air pollution concentration is measured around the source. The level of air pollution load is determined by measurements at air pollution monitoring stations.

The pollution limit value means the highest permissible level of concentration of a given substance set by Act No. 201/2012 on air protection, as amended. Air pollution limits represent values of the maximum permitted air pollution concentrations of individual pollutants in the air with differing averaging interval. The maximum number of instances exceeding the limit value is also set for selected substances. The pollution limit value is then defined for specified substances using three criteria. The first criterion is the limit value, the second represents the time averaging interval and the third is the maximum number of cases exceeding the limit value.

In addition to substances for which an air pollution limit is set (SO_2, NO_2, CO, benzene, PM_{10}, $PM_{2.5}$, benzo[*a*]pyrene, Pb, As, Cd, Ni, O_3, NO_X), many other substances, important for environmental protection, are also being measured within the National Air Quality Monitoring Network (ammonia, some ions, elemental and organic carbon, a group of aromatic hydrocarbons, volatile organic compounds, persistent organic compounds, etc.).

1.2.1 Collection of air quality data

Concentrations measured at monitoring stations form the basis for air quality assessment (Fig. 3). The measuring network is the densest in areas with the highest concentrations of pollutants, but it covers the entire CR. The backbone network of monitoring stations is the National Air Quality Monitoring Network (NAQMN) which is operated by the CHMI. It includes both automated monitoring stations (AIM) and manual air pollution stations (MIM), from which the samples are analysed in the CHMI laboratories. The National Air Quality Monitoring Network is supplemented by monitoring stations of other organizations, the measurement of which is also used in the assessment of air quality. The AQIS also includes information from the border areas of Germany, Poland and Austria, which is obtained through reciprocal data exchange.

An important basis for the assessment of air quality and for the creation of maps of air pollution characteristics is the classification of measuring stations for information exchange – EoI (EC 1997, Larssen et al. 1999). It represents a part of the database that contains so-called metadata or descriptive data. Metadata form an integral part of data collection. The official European classification was applied to all stations in the CR registered in the AQIS database. The complete EoI classification of stations consists of three key letters separated by a slash, which indicate the type of station, the type of area and the characterisation of the area. The third column only includes examples of combinations of area characteristics, in fact any logical combination is possible, with the first letter having the highest priority (Tab. 2). Further information on the classification of stations, including legislation, is provided in the Summary Tabular Survey 2019 (CHMI 2020b).
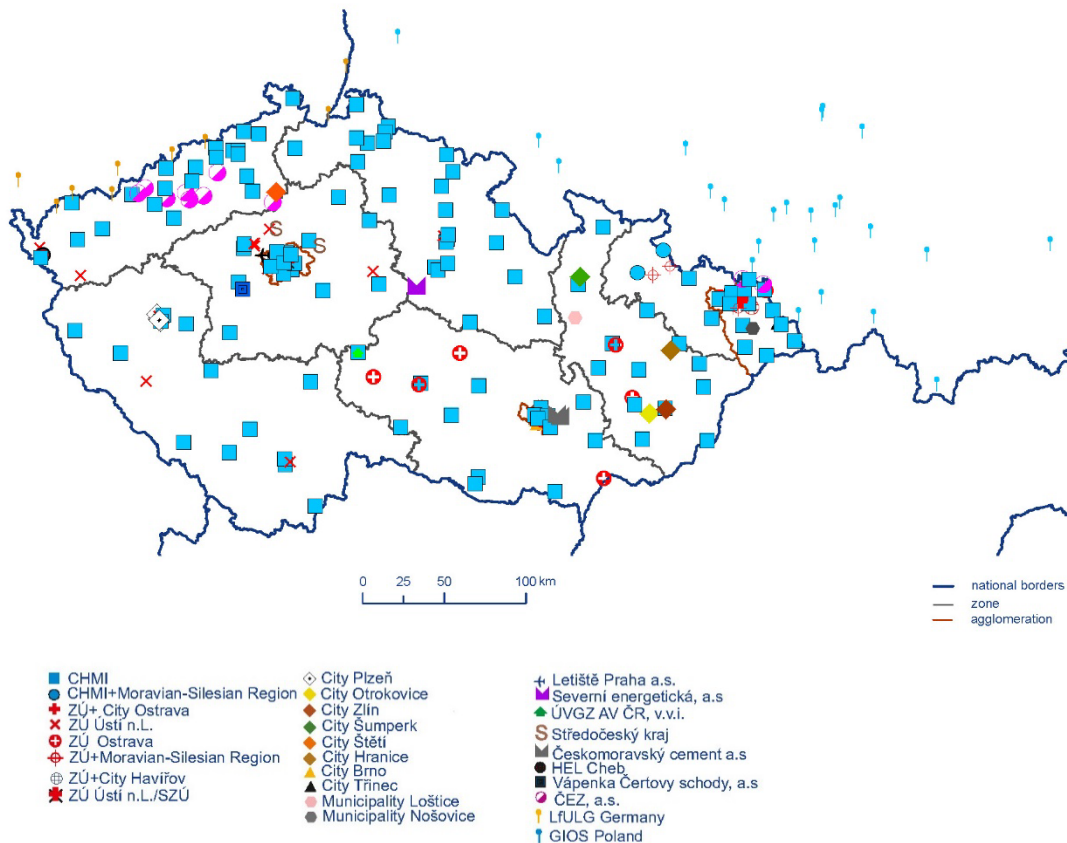

Fig. 3 Major station networks of ambient air quality monitoring, 2019

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Tab. 2 Exchange of Information (EoI) station classification

Type of station		Type of area		Characterisation of area	
Traffic	(T)	Urban	(U)	Residential	(R)
Industrial	(I)	Suburban	(S)	Commercial	(C)
Background	(B)	Rural	(R)	Industrial	(I)
				Agricultural	(A)
				Natural	(N)
				Residential/Commercial	(RC)
				Commercial/Industrial	(CI)
				Industrial/Residential	(IR)
				Residential/Commercial/Industrial	(RCI)
				Agricultural/Natural	(AN)

Fig. 4 Prague 2-Legerova hot spot AIM station (photo: CLI Prague-Libuš)

The NAQMN also includes four hot spot stations, commonly used to monitor sites or areas with high air pollution. In AQIS, this type of stations represents those focused exclusively on monitoring the impact of traffic on air pollution (paragraph A.2 of Annex No. 3 to Decree No. 330/2012 Coll.). The CHMI monitoring hot spot stations are located in heavily congested localities in Prague (Fig. 4), Brno, Ostrava and Ústí nad Labem.

The number of air pollution monitoring stations of basic pollutants of selected organizations, the data of which are stored in AQIS, has changed continuously since 1969. Most stations were in operation in the 1980s and 1990s.

In 2015, a substantial innovation took place of the National Air Quality Monitoring Network (NAQMN), the largest since the establishment of the countrywide automated air pollution monitoring in the first half of the 1990s. Within the framework of the Operational Program on the Environment, the CHMI implemented a project of comprehensive renewal of technology for monitoring and evaluation of air quality throughout the CR. In addition to the instrumentation itself, containers of automated stations, including masts for meteorological sensors, were also restored. The monitored localities and the scope of measurements were selected in accordance with the applicable legislation,

especially with regard to the need for a comprehensive national air quality assessment. The optimization of the measuring network led both to the reduction or cancellation of measurements in some localities and, conversely, to the relocation or construction of 10 measuring locations in places where continuous air quality monitoring have been lacking and where air quality mapping and evaluation was needed. At five localities, the measuring program was changed from manual to automatic, which, in addition to more detailed information on air quality, also brought about an improvement in the population's awareness of current air pollution. The NAQMN upgrade was launched in mid-February and was completed by 30 September 2015.

Within the project, 98 automated measuring stations were innovated (e.g. Fig. 5 and 6). At another 27 localities, new samplers were installed separately for sampling designated for detailed laboratory analysis (Fig. 7). 14 automatic precipitation collectors were also installed for subsequent chemical analysis of precipitation. In total, almost 500 devices were replaced.

Analytical instruments were procured to air quality laboratories, which increased the accuracy and reliability of laboratory analyses. It is worth mentioning, for example, the laboratory for determining PAHs concentrations (Fig. 8).

The successful implementation of the project enabled the CHMI to continue to maintain a high level of monitoring and evaluation of air quality in the CR and to further refine and develop key activities in this area.

Fig. 5 Churáňov AIM station (photo: CHMI Regional Office in Plzeň)

Fig. 6 Ústí nad Labem-Kočkov AIM station (photo: CHMI Regional Office in Ústí nad Labem)

Fig. 7 Vyškov MIM station – sampler (photo: CHMI Regional Office in Brno)

Fig. 8 Laboratory for determination of PAHs concentrations (photo: CHMI Regional Office in Ústí nad Labem)

1.2.2 Processing and presentation of air quality data

Concentrations measured by air pollution monitoring stations are stored in the AQIS air quality database. Data have been archived in the AQIS since the beginning of measurement, concentrations of sulphur dioxide and suspended particles from CHMI station networks in northern Bohemia, Prague and in the O/K/F-M agglomeration since 1969 and ozone concentrations in Hradec Králové since 1957. In the AQIS, detailed descriptive data on measurement sites, measurement programs and methods, classification and measurement quality are also managed.

Verification of air pollution data takes place in two steps. The employees of the CHMI regional office (CLI), i.e. the administrator of the measuring network and the professional in charge of control and verification are responsible for the first verification. They are responsible for measuring, collecting, checking and also subsequent verification of data. The second verification of air pollution data is performed in the AQIS Department continuously during the current year with the use of the database application (Fig. 9).

After uploading air pollution data, software verification is automatically started which creates a file of "suspicious data". The data from this file are assessed for credibility by an authorized professional. Using further software tools (AQIS2), all newly uploaded data to the AQIS database are checked.

Based on the results of the verification, the professional in charge of checking the data contacts the supplier to address the problem data. Verification of suspicious data is requested. In the event the supplier considers the data to be incorrect, the supplier provides the corrected data to the AQIS data administrator, who will store the data in the database.

At the end of the annual data collection, the professional in charge of checking the accuracy of the data also checks the reliability of all measured and calculated (aggregated) air pollution data.

Further information on the verification of air pollution data is provided in the Summary Tabular Survey 2019 (CHMI 2020b).

The selection of information, tables, graphs and map presentations is part of the tabular and graphic yearbooks available on the CHMI website (http://www.chmi.cz) where other overviews, including graphic representations, related air pollution are also available. With a brief delay, the Air Quality Tab also provides up-to-date results of measurements from the CHMI automated monitoring stations and other organizations in tables, as the air quality index (AQI), in graphs and as estimates of the spatial distribution of PM_{10}, SO_2, NO_2 and O_3 concentrations including a specific map of the air quality index. These maps are also presented in a newly developed CHMI+ mobile application for the Android and iOS operation systems. Currently, there is also available an up to date review of data from the Polish and Austrian automated stations, in the case of Polish stations the data are delayed by two hours due to operational reasons.
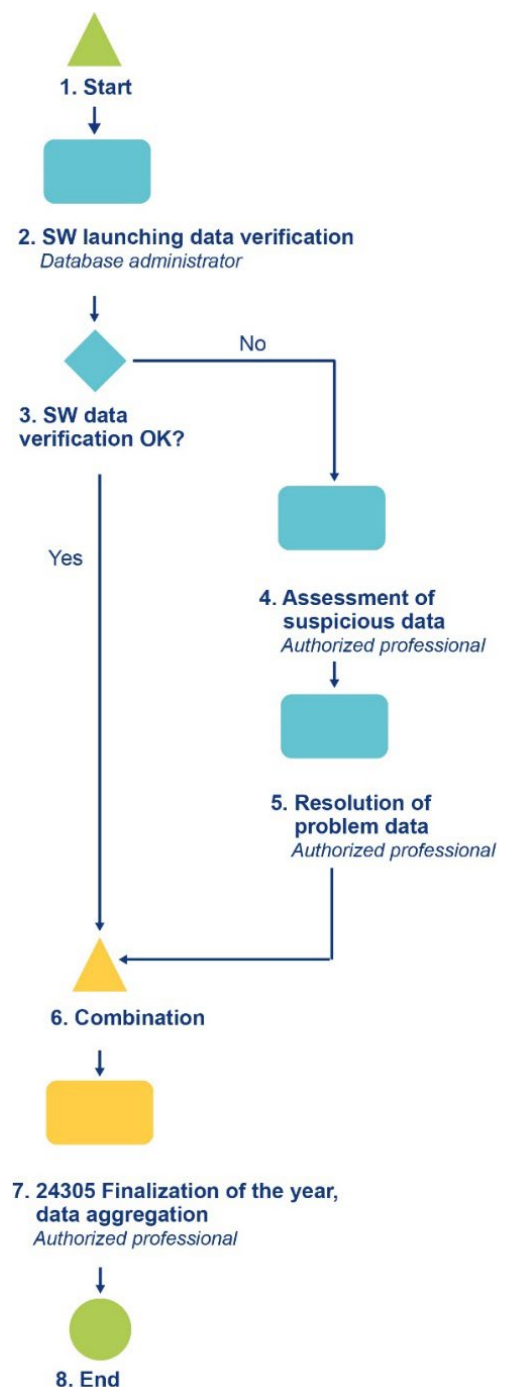
1. Start

2. SW launching data verification
Database administrator

3. SW data verification OK?
No
Yes

4. Assessment of suspicious data
Authorized professional

5. Resolution of problem data
Authorized professional

6. Combination

7. 24305 Finalization of the year, data aggregation
Authorized professional

8. End

Fig. 9 Diagram of verification of air pollution data in the AQIS

1.3 Atmospheric deposition

Atmospheric deposition refers to the flux of substances from the atmosphere to the Earth's surface. This is an important process contributing to self-cleaning of the air; on the other hand, however, it is responsible for input of pollutants into other components of the environment (hydrosphere, pedosphere, cryosphere, biosphere). Atmospheric deposition consists of both wet and dry components. The wet component is connected with the occurrence of atmospheric precipitation, both vertical (rain, snow) and horizontal (fog, rime). The dry component corresponds to the deposition of gases and particles by various mechanisms and involves the direct transfer of substances from the air to vegetation, the Earth's surface or the oceans. Unlike wet deposition, which is an episodic phenomenon due to its dependence on precipitation, dry deposition is slower, but continuous (Braniš, Hůnová 2009).

Quantification of total atmospheric deposition is very important for studying its impact on the natural environment. Determination of the individual components differs substantially in relation to the difficulty of the method and reliability of the obtained results. The CHMI has long been focusing on the specification of deposition fluxes in order to achieve results as close as possible to real deposition (Hůnová et al. 2016). One of the goals is to identify areas permanently affected by high atmospheric deposition of selected substances (Hůnová et al. 2019a).

1.3.1 Wet vertical deposition

Relatively most easily measurable is wet vertical deposition (Krupa 2002) which is associated with vertical, i.e. falling precipitation (rain, snow). Three methods are used for sampling. The "wet-only" method is a method of sampling "net precipitation", where the sampling device is exposed only for the duration of precipitation (Fig. 10). If the sampling device is exposed continuously and the sample includes, in addition to vertical precipitation, an undefined part of the dry deposition, this is a "bulk" sampling method (Fig. 11). The best possible estimate of the total atmospheric deposition is then considered to be the "throughfall" method, i.e. sampling of precipitation under the forest canopy (Fig. 12). The crowns of the trees very effectively "catch" the dry deposition, which then, together with the wet component, enters the sampling containers (Braniš, Hůnová 2009). However, this only applies to those pollutants that are not subject to significant exchange between the atmosphere and the ecosystem, such as sulphur, but not nitrogen.

In the CR, the Czech Hydrometeorological Institute (CHMI), the Czech Geological Survey (CGS), the Forest Management and Gamekeeping Research Institute (VULHM) and the Academy of Sciences of the CR, specifically the Institute of Hydrobiology (HBU AS CR), the Global Change Research Institute (ÚVGZ AS CR) and the Institute of Geology (GLÚ AS CR) provide measurements of the chemical composition of atmospheric precipitation, and thus wet vertical deposition. The CHMI stations measure net precipitation ("wet-only") at weekly intervals. An exception is the Košetice National Atmospheric Observatory, where "bulk" and "throughfall" precipitation is also taken. At the localities of other organizations, the concentration is measured in monthly (or irregular) intervals in "bulk" type precipitation in the open area, as throughfall samples. Heavy metal analyses are also performed at all stations (Fig. 13). An up-to-date overview of stations and types of sampling is given in CHMI (2020a).

To check the data on precipitation quality, the calculation of the ion balance performed by the respective laboratory analysing the collected precipitation sample is routinely used. The difference between the amount of cations and the amount of anions in the sample must meet the permitted criteria which vary slightly from organization to organization. Furthermore, a control by comparing the calculated and measured conductivity is used, which must also meet the permitted criteria. Control is also performed by analysis of blank laboratory samples, and site samples are continuously monitored and evaluated, which enable control of performance during sampling and control of ongoing changes due to transport, handling, storage and treatment of samples before chemical analysis.

Fig. 10 Automated "wet-only" sampler, Prague-Libuš station (photo: E. Svobodová)

Fig. 11 "Bulk" sampler, Prague-Libuš station (photo: E. Svobodová)

Fig. 12 "Throughfall" sampling, forest stream catchment area of the Košetice observatory (photo: J. Svobodová)
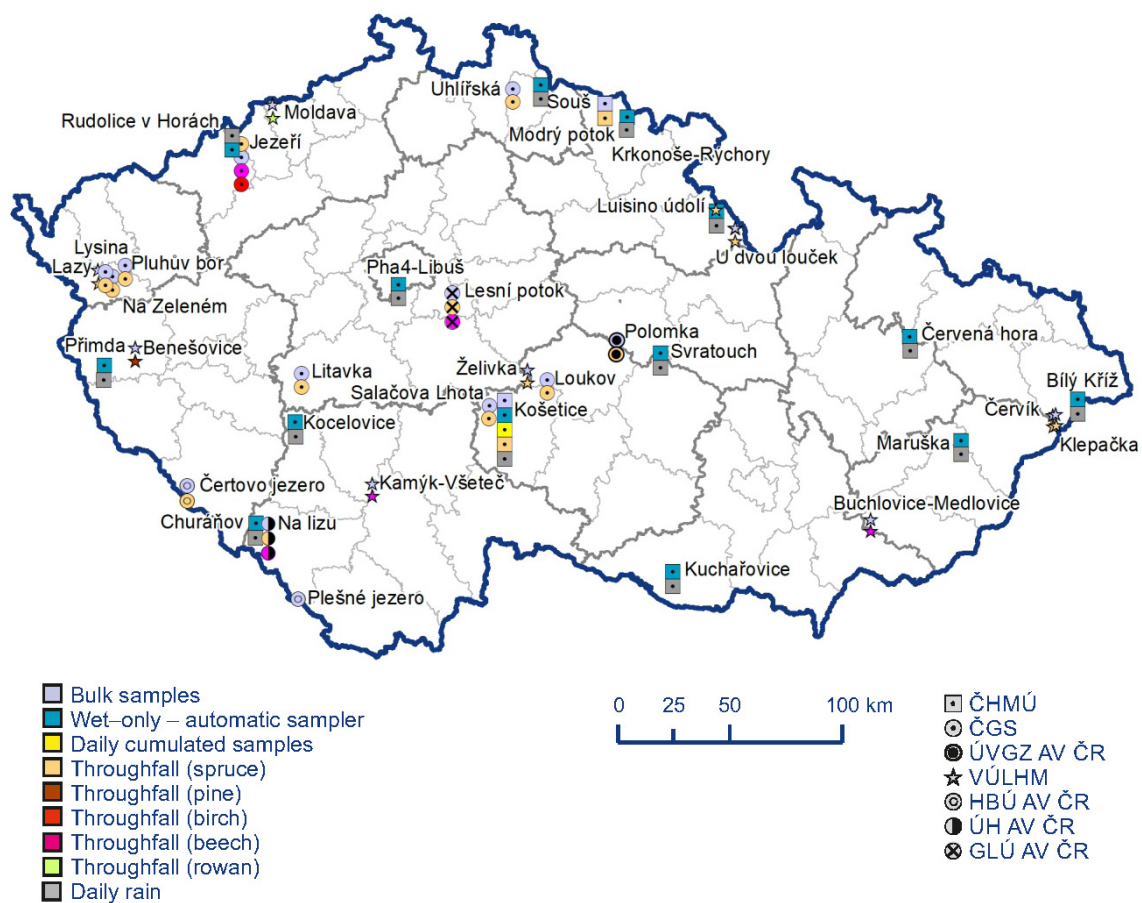
Bulk samples
Wet–only – automatic sampler
Daily cumulated samples
Throughfall (spruce)
Throughfall (pine)
Throughfall (birch)
Throughfall (beech)
Throughfall (rowan)
Daily rain

0   25   50   100 km

ČHMÚ
ČGS
ÚVGZ AV ČR
VÚLHM
HBÚ AV ČR
ÚH AV ČR
GLÚ AV ČR

Fig. 13 Station networks monitoring atmospheric precipitation quality and atmospheric deposition, 2019

1.3.2 Wet horizontal deposition

Horizontal component of the wet deposition is the most difficult component of the total atmospheric deposition to measure (e.g. Krupa 2002; Klemm, Wrzesinsky 2007). Direct sample collection is very complicated. This component is therefore measured only exceptionally and the real deposition is usually notably underestimated with respect to this component (Bridges et al. 2002; Hůnová et al. 2011).

1.3.3 Dry deposition

A method for direct measurement of dry deposition is not available, so it must be estimated using various, usually relatively complicated approaches (Wesely, Hicks 2000; Kumar et al. 2008). In the CHMI, the so-called inferential method is used to estimate dry deposition, where the dry deposition of the relevant substance is calculated as the product of its average air pollution concentration and the relevant deposition rate (Wesely, Hicks 2000). While the air pollution concentrations data of a substance are relatively reliable, the deposition rate depends on a number of factors (environmental and meteorological) and is burdened by considerable uncertainties (Braniš, Hůnová 2009).

1.4 Greenhouse gas emissions

1.4.1 Data collection

Greenhouse gases (i.e. gases that contribute to the greenhouse effect) have always been present in the atmosphere, but in recent history, the concentrations of many of them have increased in a result of human activities. Over the last century, atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halogenated hydrocarbons, i.e. greenhouse gases, have increased in a result of human activities. Greenhouse gases prevent heat from radiating back into space and cause the climate to warm. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014), CO_2 concentrations in the atmosphere have increased by 40%, mainly from fossil fuel combustion emissions and secondarily from emissions from land use change. CH_4 concentrations increased by 150% and N_2O concentrations increased by 20% compared to pre-industrial period. Ground-level ozone also contributes to the greenhouse effect. The amount of ozone generated in the lower atmosphere has increased due to emissions of nitrogen oxides, hydrocarbons and carbon monoxide.

The relatively new, man-made greenhouse gases that enter the atmosphere cause a further intensification of the greenhouse effect. This includes in particular a number of fluor-containing substances (F-gases), including HFCs (hydrofluorocarbons). HFCs are used instead of ozone-depleting CFCs in refrigerators and other applications, and their emissions are increasing rapidly. Compared to carbon dioxide, all other greenhouse gases occur at low (CH_4, N_2O) or very low concentrations (F-gases). On the other hand, these substances are more effective (per molecule) as greenhouse gases than carbon dioxide, which is considered to be the main greenhouse gas.

As a result of scientific findings that human activities affect the climate and following growing public awareness of regional and global environmental issues, climate change became part of the political agenda in the mid-1980s. The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 and two years later concluded that anthropogenic climate change is a global threat that requires an international agreement to address it. The UN has begun negotiations on a United Nations Framework Convention on Climate Change (UNFCCC), which entered into force in 1994. The long-term goal was to stabilize greenhouse gas emissions in the atmosphere at a level that would prevent harmful climate change for the planet and humanity. A key annex to the Convention is Annex I, which specifies countries that are required to report an annual inventory of greenhouse gas emissions and removals. The basic goal of the Convention was to create preconditions for the timely stabilization of global concentrations of greenhouse gases in the atmosphere at a level that would prevent dangerous interference of anthropogenic influences with the Earth's climate system. The Parties of the Convention meet annually at conferences of the parties and review the progress made so far and, where appropriate, approve strategies to achieve adopted and possibly future objectives.

The most important amendment to the Convention was agreed in 1997 in Kyoto, Japan. The Kyoto Protocol (KP) commited industrialized countries to reduce their total greenhouse gas emissions, individually or jointly, by at least 5% during the first monitoring period (2008-2012) compared to 1990. The reductions concerned emissions and sinks of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), partially (HFC) and fully fluorinated hydrocarbons (PFC) and sulphur hexafluoride (SF_6), expressed as aggregated CO_2 emissions. In the case of the CR, it was a commitment to reduce total greenhouse gas emissions by 8% compared to the reference year 1990 (for HFCs, PFCs, SF_6 and NF_3, 1995 is set as the base year). During the second control period of the KP, the EU and its Member States committed themselves to reduce their greenhouse gas emissions by 20% compared to the base year.

In December 2012, an amendment was approved at the 18th Conference of the Parties (COP-18) in Doha, Qatar, confirming the continuation of the KP and its second commitment period, which was set to eight years (2013–2020). Within the second commitment period some Parties commited to reduce their greenhouse gas emissions by at least 18% below the 1990 levels. A commitment to reduce emissions by 20% has been set for the CR, and the EU will fulfil its commitment to the Convention or the KP within the Community.

The Paris Agreement was adopted at the 21st Conference of the Parties in 2015 in Paris. It regulates the basic principles of climate protection measures which should be applied after 2020, when it is expected to enter into force. At present, negotiations are still under ongoing on specific elements of the requirements for reporting greenhouse gas emissions and removals under the rules of the Paris Agreement. The 19th Conference of the Parties agreed on Decision 24/CP.19 "Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention" which sets out reporting requirements.

As one of the parties to the UN Framework Convention on Climate Change, the CR has an obligation to prepare and regularly update national inventories of greenhouse gas emissions and sinks. In addition, membership of the European Union imposes additional requirements on the CR, such as compliance with the obligations specified in Article 7 of EU Regulation No. 525/2013.

Following the international requirements, the EU has created its own emissions trading system. In the CR, there are two interconnected systems in force - the European Emissions Trading System and flexible KP mechanisms: the Clean Development Mechanism, Joint Implementation Projects and the International Emissions Trading. The expiry of the flexible KP mechanisms is provided for in Regulation (EU) No. 525/2013 of the European Parliament and of the Council. For CHMI, as the coordinator of the inventory of emissions and sinks of greenhouse gases, the mutual interaction of the national inventory and the EU ETS system is essential. The national inventory provides background data for the calculation of emissions from relevant processes. Vice versa, when processing the national inventory, exactly measured emission factors in the EU ETS or data on emission sources of specific polluters are used, for example.

The collection of data on activities from which greenhouse gas emissions arise is generally based on official data from the Czech Statistical Office (CzSO), which are published annually, with the most representative example being the Czech Statistical Yearbook. The Czech Statistical Yearbook is usually published at the end of November, but some data are available later. Data from emissions trading, data from specific industrial associations or data from the Czech Land Surveying and Cadastre Administration are also used.

In the case of industrial processes, production data are generally not available in statistics if there are less than four related enterprises in the whole country. In such cases, inventory experts conduct specific detailed investigations in the given area.

The deadline for collecting all data is 15 November. In some cases, however, CzSO makes corrections to the data which are available later. In such cases, it is not possible to include the updated data in the reporting for the EU which is submitted by 15 January and must be considered as a preliminary output of the Czech national greenhouse gas inventory. However, all revised data are included in the final submission to the UNFCCC by 15 April (which is also submitted to the EU).

All data, both the so-called activity data and the resulting calculations, go through a detailed quality control, which takes its place throughout the inventory processing. The setting up of control procedures and internal audits is also a subject of international reviews, and if these procedures are found to be insufficient, such inventory system is marked as non-functional and the entire process of emissions trading may be suspended for the country, which has a major impact on economy. The scheme of inventory preparation is shown in Fig. 14.
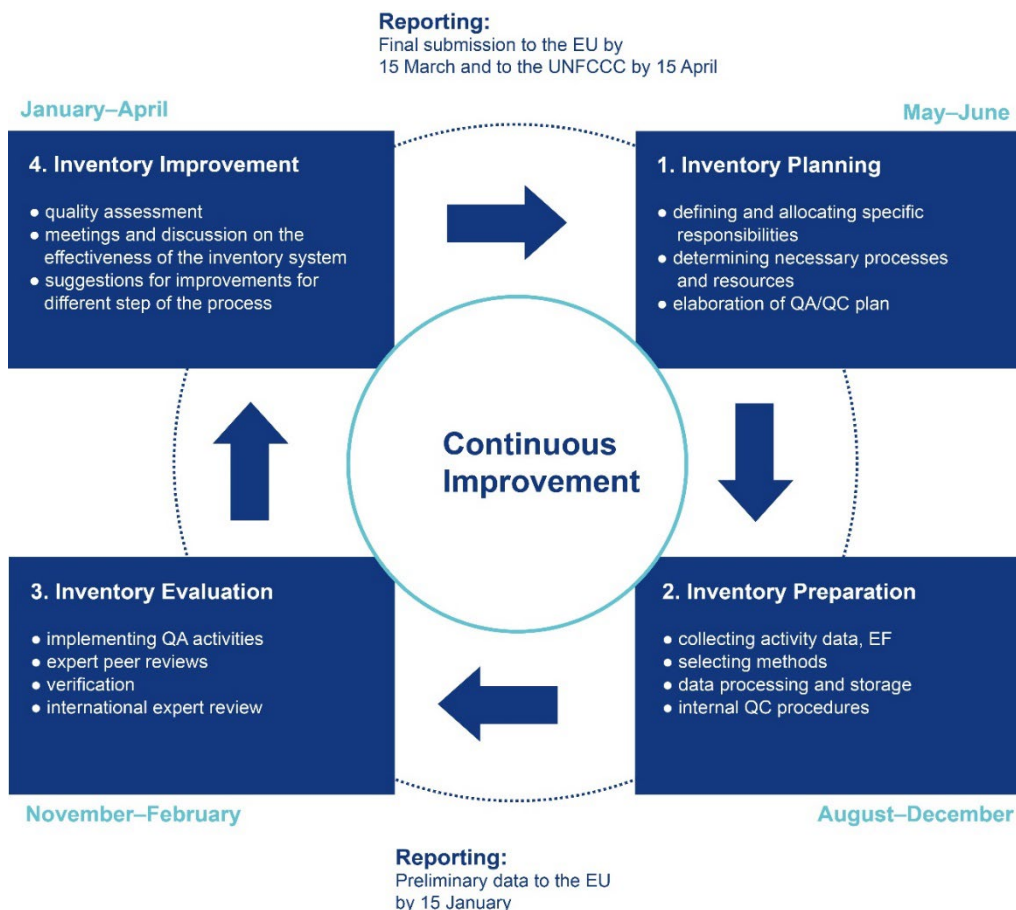
Reporting:
Final submission to the EU by
15 March and to the UNFCCC by 15 April

January–April

4. Inventory Improvement
- quality assessment
- meetings and discussion on the effectiveness of the inventory system
- suggestions for improvements for different step of the process

May–June

1. Inventory Planning
- defining and allocating specific responsibilities
- determining necessary processes and resources
- elaboration of QA/QC plan

Continuous Improvement

3. Inventory Evaluation
- implementing QA activities
- expert peer reviews
- verification
- international expert review

2. Inventory Preparation
- collecting activity data, EF
- selecting methods
- data processing and storage
- internal QC procedures

November–February

August–December

Reporting:
Preliminary data to the EU
by 15 January

Fig. 14 Scheme of inventory preparation

1.4.2 Data processing and presentation

The national inventory report together with the official reporting tables (CRF - Common Reporting Format) and all required amendments are submitted to the European Commission by 15 March each year and to the Secretariat of the United Nations Framework Convention on Climate Change by 15 April. Responsibility for the proper functioning of the National Inventory System (NIS) in the CR lies with the Ministry of the Environment which has appointed the CHMI to be the institution responsible for compiling and coordinating of GHG inventories and required data and text outputs, which are then published on the Convention portal (https://unfccc.int), similarly to reportings of other Parties. The main tasks of the CHMI are inventory management, general and cross-cutting issues, control procedures (QA/QC), communication with relevant UNFCCC and EU bodies, etc. The Czech national inventory system has included a number of research institutions, which are being part of it on a long-term basis. These institutions are responsible for compiling of the emission inventories in the sectors, from which emissions of greenhouse gases arise. The functioning of the national inventory system is also subject to reviews conducted by the UNFCCC as well as the work of the sectoral experts. The resulting official inventory is then prepared by the CHMI and approved by the Ministry of the Environment and other governmental. Fig. 15 shows a diagram of the functioning of the national inventory system in the CR.

One of the basic requirements of the Convention, the KP and possible other amendments is timely, accurate, transparent, consistent and internationally comparable systematic monitoring of greenhouse gas emissions. These are valid principles of the so-called TACCC - transparency, accuracy, completeness, comparability, consistency.

The inventory includes not only anthropogenic emissions of direct greenhouse gases CO_2, CH_4, N_2O, HFC, PFC, SF_6, NF_3, but also indirect greenhouse gases NO_X, CO, NMVOC and SO_2. Indirect means that they do not directly contribute to the greenhouse effect, but that their presence in the atmosphere

can affect the climate in various ways. As mentioned above, ozone (O_3) is also a greenhouse gas that is produced by the chemical reactions of its precursors: nitrogen oxides, hydrocarbons and/or carbon monoxide.

The inventory of greenhouse gas emissions and sinks is prepared in accordance with the methodological guidelines of the Intergovernmental Panel on Climate Change, IPCC 2006 Guidelines. Also, great emphasis is placed on the refinement of these internationally valid methodologies, with regard to the greatest possible consideration of country specific conditions. In case that the methodological procedures are refined, there is a need, in many cases, to recalculate the reported emissions for the whole time series. This maintains a time-series consistent approach to emissions reporting.

Data from all sectors are then processed according to UNFCCC requirements into official reporting tables and the reporting document. Each chapter must contain a description of the activities from which the emissions of greenhouse gases arise, a detailed description of methodological procedures, results, possible recalculations, and last but not least, information on the control procedures performed and possible uncertainties of emission estimates. All this must be carried out in great detail and is inspected annually by both the UNFCCC and the EU. If a major problem is found, it must be corrected immediately and the entire inventory resubmitted.
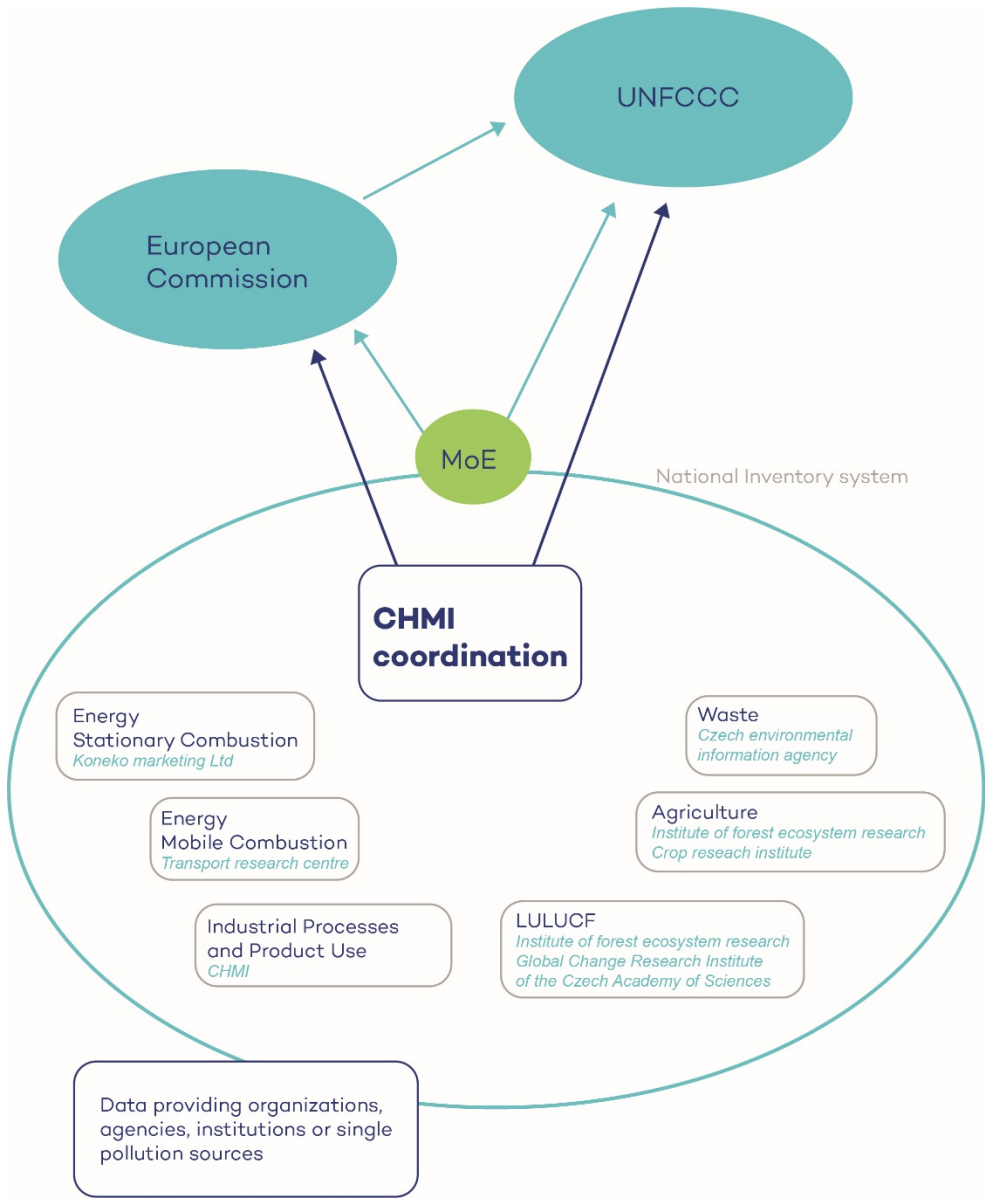

Fig. 15 Diagram of the functioning of the national inventory system in the CR

2 Evaluation

This chapter defines the tools used to assess air quality. These include meteorological and dispersion conditions that significantly affect both emissions and air pollution concentrations. Furthermore, there is a description of the methodology for creating areal maps which present the areal distribution of the concentration estimate.

2.1 Meteorological and dispersion conditions

Apart from explicit air pollution sources, meteorological conditions significantly affect air quality. They enable the dispersion of pollutants in the air, have an effect on the amount of emissions from anthropogenic and natural sources, affect the formation of secondary pollutants, and the rate of their removal from the air.

2.1.1 Dispersion conditions

The dispersion conditions are determined primarily by the stability of the boundary layer of the atmosphere and the flow velocities in this layer. The greater the stability of the boundary layer, the less vertical air mixing occurs. The stability depends on evolution of the temperature with the height. In the most stable situations, the air temperature rises with height (inverse stratification) and the conditions for vertical mixing are the least favourable. As a result, pollutants accumulate in the atmosphere and consequently increase in their concentrations. With unstable stratification, the temperature decreases with height faster than would correspond to normal atmospheric conditions. The ordered thermal convection and thermal turbulence then manifest (Bednář 2008). Wind speed and direction affect the horizontal dispersion of emissions, leading to faster diffusion. This reduces pollutant concentrations and cleans the air quickly. In addition, stronger winds lead to the development of mechanical turbulence, thus contributing to vertical mixing.

One of the ways in which the dispersion conditions can be expressed numerically is in terms of the ventilation index (VI) which is defined as the product of the depth of the mixing layer and the average wind speed in it. Under the conditions in the CR, the ventilation index expressed in this way generally attains values from hundreds up to tens of thousands $m^2.s^{-1}$, where values above 3,000 $m^2.s^{-1}$ are designated as good dispersion conditions, values between 1,100 and 3,000 $m^2.s^{-1}$ are considered moderately poor and values below 1,100 $m^2.s^{-1}$ as poor. Situations with poor dispersion conditions do not necessarily mean occurrence of high pollutant concentrations. Important is the duration of the situation, the starting level of pollution, the distribution of sources, and their emissions to the layer under the inversion. However, substantial and extensive exceeding of the pollution level limits occurs almost exclusively under moderately poor and poor dispersion conditions. The frequency of the occurrence of various types of dispersion conditions strongly depends on the time of day and season of the year.

2.1.2 Effect of meteorological conditions on emissions

Meteorological conditions have the greatest effect on anthropogenic emissions from heating. Emissions from heating are determined on the basis of calculation of heating days and the temperatures that occurred during these days. Long-distance heat supply is regulated by Decree No.

194/2007 Coll.[3] Households with their own heating equipment behave somewhat differently from central heat suppliers. Consequently, for the purposes of this yearbook, in contrast to the Decree, heating days are considered to be days during which the average daily temperature at the relevant site decreased below 13 °C. Temperature conditions in the heating season (January–May, September–December) or parts thereof are characterized in terms of degree-days – i.e. the sum of the differences in the reference indoor temperatures and the average daily outdoor temperatures on heating days:

$$D_{t_{ref}} = \sum_{\substack{heating \\ days}} \left(t_{ref} - t_d \right)$$

where D_{tref} are degree-days, t_{ref} is the reference temperature of the indoor air (21 °C) and t_d is the average daily temperature on the individual heating days.

Lower temperatures can lead to increase of combustion emissions from motor vehicles, especially during cold starts (ATEM 2012; Chan et al. 2013; Vojtíšek 2013). Volatile organic compounds (VOCs) emissions from solvents and storage and distribution of petrol also depend on the temperature. The temperature and photosynthetically active components of solar radiation affect biogenic emissions of non-methane volatile organic compounds (e.g. isoprene and terpenes) which act as precursors for secondary organic aerosols and tropospheric ozone. Emissions from forested areas are especially important (e.g. Bednář et al. 2013; Zemánková et al. 2010). Wind of a speed above approximately 4 m·s^{-1} can cause resuspension, i.e. eddying and repeated lifting of already settled particles back into the air. Meteorological conditions also affect the degree and rate of evaporation of persistent organic substances from the soil, where they were deposited mainly through agricultural activities.

2.1.3 Effect of meteorological conditions on the formation of secondary pollutants and the atmospheric chemistry

Meteorological conditions, especially the temperature, relative humidity of the air and solar radiation, directly affect the chemical and physical processes taking place among the pollutant substances in the air (e.g. Baek et al. 2004). Meteorological conditions can also have an indirect impact, e.g. intense mixing can lead to dilution of emitted substances and thus to a reduction in the rate of a reaction. Solar radiation is decisive during photochemical reactions. In the summer, high temperatures and especially intense solar radiation contribute to high tropospheric ozone concentrations (Blažek et al. 2013).

---

[3] According to Decree No. 194/2007 Coll., supply of heat is commenced in the heating season (i.e. the period from 1 September to 31 May), if the average daily temperature of the outdoor air at the site decreases below +13 °C on two subsequent days and, according to the development of the weather, an increase in this temperature above +13 °C cannot be expected on the following days. Heating in the heating season is reduced or interrupted if the average daily temperature of the outdoor air at the relevant site or location increases above +13 °C on two subsequent days and, following the development of the weather, a decrease in this temperature cannot be expected on the next day. Heating is renewed if the average daily temperature of the outdoor air decreases below +13 °C.

2.2 Creation of ambient air pollution and atmospheric deposition maps

2.2.1 Ambient air pollution maps

Directive No. 2008/50/EC on ambient air quality and cleaner air for Europe, which is implemented into the Czech legislation (i.a. Decree No. 330/2012 Coll.), requires that the air quality be evaluated in all the zones and agglomerations of each member state. It further requires that the primary source of the evaluation be the results of stationary measurements. In the creation of air pollution maps, the measured concentrations may be supplemented by modelling and indicative measurements, so that the resultant estimate provides sufficient information on the spatial distribution of the pollutant concentrations in the air. The requirement to use stationary measurements as primary sources of information is related especially to areas in which the pollutant concentrations exceed the upper assessment threshold. This requirement is applied to the whole territory of the CR to ensure uniformity of the map creation methodology.

The basic source of data for the creation of air pollution maps are therefore the concentrations of pollutants measured at individual measuring stations. There are only a limited number of monitoring stations. Therefore, in addition to the measured (primary) data, various additional (secondary) data are used for preparation of the maps, which provide comprehensive information about the entire territory and simultaneously exhibit a regression relation with the measured data. The main secondary source of information consists in models of pollution transport and dispersion, based on data from emission inventories and meteorological data. In the CR, mainly the CAMx Eulerian chemical dispersion model is used, supplemented by the SYMOS Gaussian model and the European EMEP Eulerian model. In addition, for individual pollutants, data on the altitude and population density are used (for details, see Annex I in the graphic yearbook (CHMI 2020a)). Combination of primary and secondary data takes an advantage of both the precision of the primary measured data and comprehensive coverage of the entire territory by the secondary data. In regular map creation for the yearbook, the linear regression model is used with subsequent interpolation of its residuals. The kriging and IDW models are used as interpolation methods (for details, see Annex I in the graphic yearbook (CHMI 2020a)).

Urban and rural types of air pollution differ in character; in general, urban pollution is affected by emissions and is generally higher than rural air pollution. An exception is represented by ground-level ozone pollution which exhibits the opposite behaviour. Thus, urban and rural map layers are created independently and the resultant map is a product of combination of the urban and rural maps using the grid of population density. For certain pollutants (PM_{10}, $PM_{2.5}$, NO_2, NO_x), the traffic map layer is considered in addition to the urban and rural map layers. This layer is merged with the urban and rural background layers using the grid of traffic emissions. The measured air pollution data from the background rural stations are used as primary data for construction of rural maps. Air pollution data from urban and suburban background stations are used for urban maps. Data from traffic stations are used for the traffic layers. Simultaneously, the individual stations are classified according to the AQIS database.

The maps are created using geographic information systems (GIS). The main data source is the AQIS relational database of measured emissions and the chemical composition of atmospheric precipitation. The maps are constructed with spatial resolution of 1x1 km, in the WGS 1984 UTM Zone 33N projection. Annex I in graphic yearbook (CHMI 2020a) gives detailed specification of mapping for the individual pollutants.

Since 1994, the digital DMÚ 200, DMR-2, DMÚ25 and later the ZABAGED layers have been used as the basis for the basic geographic and thematic layers in the standard projection (WGS 1984 UTM Zone 33N projection). The data provided by CSO have been used for updated layers of administrative classification.

Mapping of rural and urban (or traffic) layers

Maps of rural and urban background pollution (and, where applicable, also traffic pollution) are prepared separately, constructed on the basis of combinations of primary (measured) and secondary (model and other supplementary) data (Horálek et al. 2007) The methodology employed consists in the linear regression model with spatial interpolation of its residuals. This methodology enables the use of supplementary data for the entire mapped territory. Where there are no suitable supplementary data, simple interpolation of the measured data is used. The estimate is calculated using the relationship

$$\hat{Z}(s_0) = c + a_1.X_1(s_0) + a_2.X_2(s_0) + \ldots + a_p.X_p(s_0) + \eta(s_0), \quad (1)$$

where $\hat{Z}(s_0)$ is the estimated concentration value at point s_0,
$X_i(s)$ are the various supplementary parameters at point s_0 for $i = 1, 2, \ldots, p$,
$c, a_1, a_2, \ldots$ are the parameters of the linear regression model,
$\eta(s_0)$ is the spatial interpolation of the residuals of the linear regression model at point s_0, calculated on the basis of the residuals at the points of measurement.

The interpolation is performed either using the inverse distance weighting method (IDW) or using the ordinary kriging (specification for individual pollutants is given in Annex I in the graphic yearbook (CHMI 2020a)). The IDW method is a simple deterministic method, where the weight of the individual measuring stations in the interpolation depends only on their distance from the estimated point. On the other hand, kriging is a more advanced geostatistical method taking into account the structure of the air pollution field. However, the IDW method has the advantage that the interpolation respects the measured values in the points of the measuring stations. Kriging does not, in general, respect the measured values. A solution lies in interpolation using kriging and applying IDW to its residuals at the measuring sites.

Interpolation of residuals using IDW is calculated using the relationship

$$\hat{R}(s_0) = \frac{\sum_{i=1}^{N} \frac{R(s_i)}{d_{0i}}}{\sum_{i=1}^{N} \frac{1}{d_{0i}\beta}}, \quad (2)$$

where $\hat{R}(s_0)$ is the estimate of the field of residuals at point s_0,
$R(s_i)$ is the residual of the linear regression model at the measuring site s_i,
N is the number of surrounding stations used in the interpolation,
d_{0i} is the distance between points s_0 and s_i,
β is the weight.

For ordinary kriging, the interpolation of the residuals is calculated using the relationship

$$\hat{R}(s_0) = \sum_{i=1}^{N} \lambda_i R(s_i), \quad (3)$$

where $R(s_i)$ is the residual of the linear regression model at the measurement site s_i,

$\lambda_1, \ldots, \lambda_N$ are the weights derived using the theory of spatial statistics (see Cressie 1993) from the system of $N + 1$ equations for the unknown λ_i and m:

$$\sum_{j=1}^{N} \lambda_j \cdot \gamma(d_{ij}) + \gamma(d_{0i}) - m = 0 \quad \text{for} \quad i = 1, \ldots N,$$
$$\sum_{i=1}^{N} \lambda_i = 1, \quad (4)$$

where $\gamma(d_{ij})$ is the value of the estimated variogram (see below) for the distance d_{ij},

d_{ij} is the distance between sites s_i a s_j,

m is the so-called Lagrange multiplier allowing the sum of weights λ_i to be equal to one.

The variogram is a measure of spatial correlation and expresses the dependence of the inter-point variability on the distance between the points (e.g. Cressie 1993). The estimated variogram is created by fitting the spherical curve to an empirical residual field variogram (cluster of points) which is calculated using the relationship

$$2\gamma_v(h) = \frac{1}{n}\Sigma_{i,j;d_{ij}=h\pm\delta}\left(R(s_i) - R(s_j)\right)^2 \qquad (5)$$

Where

n is the number of pairs of stations si and sj, whose mutual distance $h\pm\delta$,

δ is tolerance

The spherical curve and the variogram range, nugget and sill are illustrated in Fig. 16. The calculated urban and rural (and, as appropriate, also traffic) layers are subsequently merged.
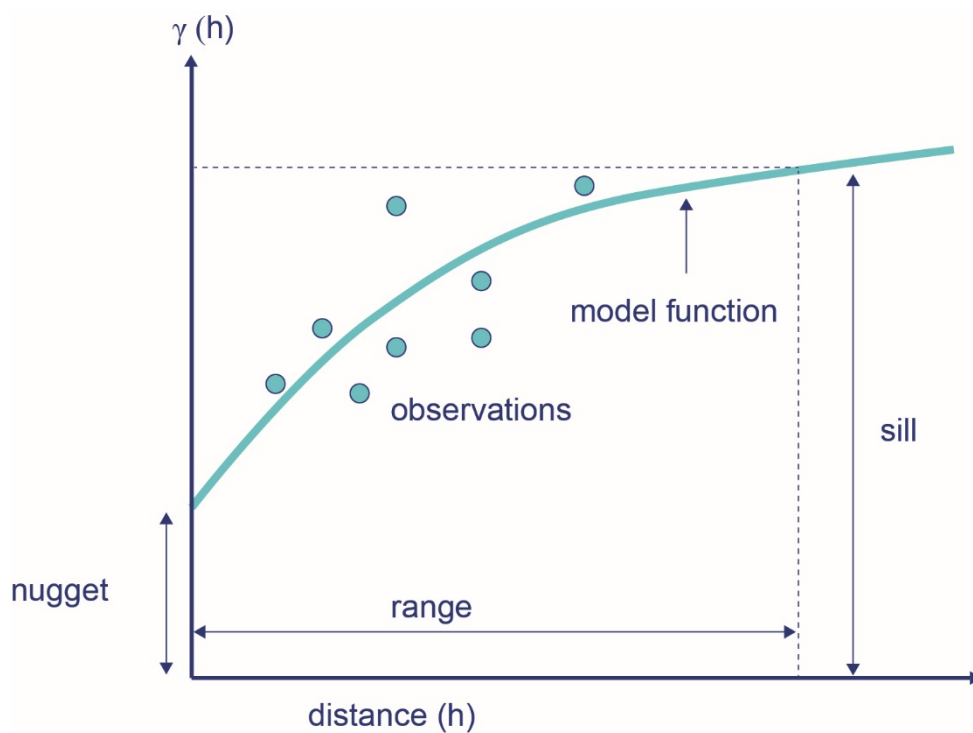

Fig. 16 Diagram showing the variogram parameters and fitted spherical curve

Merging of urban and rural (and, as appropriate, traffic) layers

The population density layer is used for merging the urban and rural layers (Horálek et al. 2007; De Smet et al. 2011). Merging is carried out using the relationship

$$
\begin{aligned}
\hat{Z}(s_0) &= \hat{Z}_r(s_0) && \text{for } \alpha(s_0) \leq \alpha_1 \\
&= \frac{\alpha_2 - \alpha(s_0)}{\alpha_2 - \alpha_1} \cdot \hat{Z}_r(s) + \frac{\alpha(s_0) - \alpha_1}{\alpha_2 - \alpha_1} \cdot \hat{Z}_u(s_0) && \text{for } \alpha_1 < \alpha(s_0) < \alpha_2 \\
&= \hat{Z}_u(s_0) && \text{for } \alpha(s_0) \geq \alpha_2
\end{aligned}
\qquad (6)
$$

where $\hat{Z}(s_0)$ is the final estimate of the concentration at point s_0,
         $\hat{Z}_r(s_0)$, $\hat{Z}_u(s_0)$ is the concentration at point s_0 for the rural or urban map,
         $\alpha(s_0)$ is the population density at point s_0,
         α_1, α_2 are the classification intervals corresponding to the population density (Annex I in the graphic yearbook (CHMI 2020a).

The entire concept of separate mapping of rural and urban pollution is based on the assumption that $\hat{Z}_r(s_0) \leq \hat{Z}_u(s_0)$ for all common pollutants except for ozone, where $\hat{Z}_r(s_0) \geq \hat{Z}_u(s_0)$ for ozone. For areas where this assumption is not fulfilled, a layer created similarly to the urban and rural layers is used; nonetheless, it is created on the basis of all the background stations without distinguishing between urban and rural stations.

If traffic pollution is also mapped for the relevant pollutant, the traffic layer is added to the background (merged urban and rural) layer using the grid of traffic emissions:

$$
\begin{aligned}
\hat{Z}(s_0) &= \hat{Z}_b(s_0) && \text{for } \tau(s_0) \leq \tau_1 \\
&= \frac{2}{3}\cdot\hat{Z}_b(s_0) + \frac{1}{3}\cdot\left(\frac{\tau_2 - \tau(s_0)}{\tau_2 - \tau_1} \cdot \hat{Z}_b(s) + \frac{\tau(s_0) - \tau_1}{\tau_2 - \tau_1} \cdot \hat{Z}_t(s_0) \right) && \text{for } \tau_1 < \tau(s_0) < \tau_2 \\
&= \frac{2}{3}\cdot\hat{Z}_b(s_0) + \frac{1}{3}\cdot\hat{Z}_t(s_0) && \text{for } \tau(s_0) \geq \tau_2
\end{aligned}
\qquad (7)
$$

where $\hat{Z}(s_0)$ is the final estimate of the concentration at point s_0,
         $\hat{Z}_b(s_0)$ is the concentration at point s_0 for the background layer,
         $\hat{Z}_t(s_0)$ is the concentration at point s_0 for the traffic layer,
         $\tau(s_0)$ are the emissions from traffic at point s_0,
         τ_1, τ_2 are classification intervals corresponding to emissions from traffic (Annex I in the graphic yearbook (CHMI 2020a)).

The above function is based on the assumption that $\hat{Z}_b(s_0) \leq \hat{Z}_t(s_0)$ for common pollutants, except ozone, where $\hat{Z}_b(s_0) \geq \hat{Z}_t(s_0)$. For areas where this assumption is not met, the background layer $\hat{Z}_b(s_0)$ is used.

2.2.2 Atmospheric deposition maps

Maps of total annual deposition for sulphur, nitrogen and hydrogen ions, and maps of wet deposition for sulphur, nitrogen, hydrogen ions, lead, cadmium, chloride and nickel ions are regularly prepared for the Air Pollution in the CR publication. Dry deposition maps are also presented for sulphur, nitrogen, hydrogen ions, lead and cadmium.

Maps of wet deposition of individual ions were created from the fields of ion concentrations in precipitation (based on annual mean weighted concenrations calculated from measured values) and from the fields of total annual precipitation on the basis of data from CHMI precipitation gauging

stations, taking into account the effect of altitude on the amount of precipitation. In creating the fields of wet deposition, the results of "wet-only" samples at individual stations are preferred over "bulk" samples and weekly sampling is preferred over monthly sampling. Data from the network of stations where measurements are performed by CGS, VÚLHM and GIOS, based on monthly collection of "bulk" samples, are modified in preparation of wet deposition maps by empirical coefficients expressing the ratios of the individual ions in "wet-only" and "bulk" samples (values for the individual ions range from 0.74 for NH_4^+ to 1.06 for H^+). The fact that the ratio is greater than 1 for the H^+ ion can be explained by the fact that solid particles contained in "bulk" type samples react with hydrogen cations, reducing their concentrations (Ranalli et al. 1997).

Dry deposition of sulphur and nitrogen is calculated on the basis of the fields of the annual mean concentrations of SO_2 and NO_x for the CR and the deposition rate for sulphur dioxide of 0.7 cm·s^{-1} or 0.35 cm·s^{-1} respectively, and nitrogen oxides of 0.4 cm·s^{-1} or 0.1 cm·s^{-1} respectively, for forested or treeless areas respectively (Dvořáková et al. 1995). An updated layer of forested areas in 1 x 1 km grid is prepared for the yearbook presenting the assessment of air pollution since 2019 on the basis of vector data of forest areas from the SALSC ZABAGED geodatabase (Hůnová et al. 2019b).

By summing the maps of wet and dry deposition of sulphur and nitrogen, maps of total deposition are created.

The map of wet deposition of hydrogen ions is created on the basis of measured pH values in precipitation. The map of dry deposition of hydrogen ions corresponds to the deposition of SO_2 and NO_x gases on the basis of stoichiometry, assuming their acidic reaction in the environment. The map of total hydrogen ion deposition is created by the sum of wet and dry deposition maps.

The fields of dry deposition of lead and cadmium contained in aerosol is prepared from the concentration fields of these metals in the air (or on the basis of pollution value fields for the annual average PM_{10} concentrations and the values of IDW interpolation of the fraction of the individual metal in the dust). For deposition rate for cadmium contained in aerosol, values of 0.27 cm·s^{-1} for forests and 0.1 cm·s^{-1} for treeless terrain were used, for lead 0.25 cm·s^{-1} for forests and 0.08 cm·s^{-1} for treeless terrain (Dvořáková et al. 1995).

Throughfall deposition of sulphur

The map of throughfall deposition of sulphur is created for places with vegetation based on the field of sulphur concentrations in throughfall precipitation and from the verified precipitation field modified in percentage by the amount of precipitation measured under vegetation at individual stations (this value is usually in the range of 50-90% of the precipitation total in the open area). Throughfall deposition generally involves wet vertical and horizontal deposition (from fog, low clouds and rime) and dry deposition of particles and gases. For sulphur, for which the internal cycle in vegetation is negligible, it should be a good estimate of the total deposition.

In some mountain areas of the country, the long-term throughfall deposition values are higher than the values of total sulphur deposition determined as the sum of wet (only vertical) and dry deposition from SO_2. This increase can be attributed to the contribution from deposition from fog, low clouds and rime (horizontal deposition), which is not included in total deposition because of its uncertainty. Rime and fogs are usually very concentrated and in mountain areas and areas with frequent occurrence of fogs (valley fogs, fogs close to water courses and lakes) can contribute substantially to the deposition of sulphur and other elements. The locally highly variable character of this deposition is also a problem as extrapolation over a larger area can lead to inaccuracies. For mountain areas, sulphate deposition from fogs and rime is considered to correspond to 50–90% of the "bulk" type deposition on an average over a longer period lasting several years (Tesař et al. 2000; Tesař et al. 2005). In some independently evaluated years, the ratio of deposition of sulphates from fog and rime and deposition of the "bulk" type even exceeded 100%.

Throughfall deposition further includes a contribution by dry deposition of S from SO_4^{2-} contained in particulate aerosol. Based on the data on sulphate concentrations in aerosol for 2014 from two stations (Churáňov and Košetice) and applying a deposition rate of 0.25 cm·s^{-1} (Dvořáková et al. 1995), the

dry deposition of S from SO_4^{2-} attained an average value of 0.04 g·m^{-2} per year for forested areas (Churáňov = 0.026 g·m^{-2} per year, Košetice = 0.058 g·m^{-2} per year). Because of the limited number of locations where the sulphate concentration in aerosol is monitored, this is only a very rough estimate.

The map of throughfall deposition can be considered as an illustration of the values that total sulphur deposition (including horizontal deposition and dry deposition of S from SO_4^{2-} in particulate aerosol) can attain because, unlike other pollutants, internal circulation of sulphur in vegetation is negligible (Draaijers et al. 1997).

For the graphic yearbooks during the 2008-2018 period, throughfall deposition was calculated using the forested areas layer of the SALSC ZABAGED database with a finer grid (500x500 m), where the total forest area is 26,428 km^2. For this reason, the total values of throughfall deposition since 2001 were recalculated with this forest layer in order to make a comparison with data after 2007. An updated layer of forested areas in the 1x1 km grid has been prepared for the yearbook presenting the air pollution assessment since 2019 based on vector data of forest areas from the SALSC ZABAGED geodatabase (Hůnová et al. 2019b).

3 Glossary of terminology

Atmospheric deposition
Flux of substances from the atmosphere to the Earth's surface. It is an important process contributing to self-cleaning of the air; on the other hand, however, it is responsible for input of pollutants into other components of the environment.

Emissions
Release of pollutants or greenhouse gases into the air and atmosphere.

F-gases
Fluorinated greenhouse gases; hydrocarbons whose molecule contains a fluorine atom.

Chemical transport model
Method for estimating concentrations in an area based on emission and meteorological inputs, taking into account the physical and chemical properties of individual substances and their transport in the atmosphere.

IDW
A simple method of interpolation, where the weight of individual measuring stations is a measure corresponding to the inverse of the distance to the point of interest.

Air quality
Air quality is characterised by concentration of harmful substances in the ambient air. The pollutant contained in the air comes into contact with the recipient (human, plant, animal, material) and has a negative effect on it. Pollution of the air occurs after the physical-chemical conversion of emissions released to the air.

Interpolation
Estimation of a quantity (e.g. air pollution concentration) in an area on the basis of known values of this quantity at a limited number of points (e.g. in measuring localities).

Kriging
Interpolation method using spatial correlation to determine the weight of individual measuring stations.

Linear regression model
Method of estimating one quantity on the basis of other quantities using their statistical interrelations.

Boundary layer
The boundary layer refers to the part of the atmosphere adjacent to the Earth's surface in which mechanical and thermal turbulence develops as a result of interaction with the Earth's surface and in which there is an intense vertical transfer of momentum, heat, water vapour and polluting substances.

Sampling of the "bulk" type
Sampling of precipitation collecting, in addition to "wet-only" precipitation, an undefined part of the dry deposition to containers exposed continuously, usually for a period of week or month.

Sampling of the "throughfall" type

The so-called tree subcanopy precipitation or subcanopy deposition sampling is performed in the forest area in regularly or irregularly placed continuously exposed sampling containers for a period of usually one month. This sampling is considered to be the best estimate of the total exposure of some substances.

Sampling of the "wet-only" type

Collection of so-called net precipitation using an automatic sampler exposed only for the duration of the precipitation episode.

Resuspension

Resuspension of particles (also secondary dusting), i.e. particles originally deposited which are subsequently re-released by swirling into the air by wind or by the effect of turbulent flow caused by a passing vehicle.

Greenhouse gas

Gas that contributes to the Earth's greenhouse effect.

Mixing layer

Mixing layer means the layer of air between the Earth's surface and the lower boundary of the lowest holding temperature layer.

4 List of abbreviations

AIM	Automated Air Quality Monitoring
AQI	Air Quality Index
AQIS	Air Quality Information System
ATEM	Studio of Ecological Models
CAMx	Comprehensive Air Quality Model with Extensions
CDV	Transport Research Centre
CFC	Chlorofluorocarbon
CGS	Czech Geological Survey
CLI	Central Laboratories of Ambient Air Quality Monitoring
CR	CR
CRF	Common Reporting Format
CSO	Czech Statistical Office
DMÚ	digital terrain model
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmissions of Air Pollutants in Europe
EoI	Council Decision 97/101/EC on exchange of information
GIS	Geographic Information System
HBÚ AV ČR	Institute of Hydrobiology of the Academy of Sciences of the CR
HFC	hydrofluorocarbons
CHMI	Czech Hydrometeorological Institute
IDW	Inverse Distance Weighing
IIR	Report on the implementation of emission inventories
IPCC	Intergovernmental Panel on Climate Change
ISPOP	System of the Fulfilling Reporting Obligations
KP	Kyoto Protocol
LRTAP	Convention on Long-range Transboundary Air Pollution
MIM	Manual Air Quality Monitoring
MOE	Ministry of Environment

NAQMN	National Air Quality Monitoring Network
NFR	Nomenclature for Reporting Codes
NIS	National Inventory System
PCB	polychlorinated biphenyls
PCDD/F	polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans
PFC	perfluorocarbons
POPs	persistent organic pollutants
QA / QC	Quality assurance and quality control
REZZO	Register of Air Pollution Emissions Sources
SALSC	State Administration of Land Surveying and Cadastre
SLDB	Census of persons, houses and apartments
SP	solid pollutants
SPE	summary operating records
SPM	suspended particulate matter
STK	Technical Inspection Station
SVÚOM	National Research Institute for the Protection of Materials
SYMOS	System for Modelling of Stationary Sources
TSP	total suspended particulates
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
ÚVGZ AV ČR	Global Change Research Institute CAS
VOC	volatile organic compounds
VÚLHM	Forest Management and Gamekeeping Research Institute
VÚZT	The Agricultural Technology Research Institute
ZABAGED	Fundamental Base of Geographic Data of the CR
ZSJ	basic settlement unit

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Data collection, processing and evaluation systém

Pollution and air quality
Atmospheric deposition
Greenhouse gases