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6. SELECTED ANALYSIS

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6.1 DESIGN, SCIENTIFIC GOALS AND CHALLENGES OF THE ATMOSPHERIC STATION KŘEŠÍN U PACOVA

Alice Dvorská, Vlastimil Hanuš, Milan Váňa, Naděžda Zíková, Vladimír Janata, Marian Pavelka

6.1.1 Introduction

Natural and anthropogenic substances and processes (e.g. changes in atmospheric concentrations of GHG, aerosols, land cover and solar radiation) influence the energy budget of the Earth and are the drivers of climate change. The human influence on the climate system is evident from the increasing GHG concentrations in the atmosphere, positive radiation forcing, observed warming, and understanding of the climate system [18]. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change [17] stated in 2007, that progress in understanding spatial and temporal changes of climate is achieved by improvements and extension of datasets and data analyses, a broader geographical coverage of the observations, better understanding of uncertainties and a wider variety of measurements. An improvement in projections of climate change and its impacts beyond 2050 was said to require an improved understanding of sources of uncertainty and enhancements in systematic observation networks. Since 2007, measurement capabilities have continued to advance [18].

The quantification and localization of GHG sources and sinks is a high research priority for understanding the global carbon cycle, as well as for designing systems for monitoring the effectiveness of GHG control and emission reductions measures. Variations in observed atmospheric GHG concentrations are used to derive information about regional sources and sinks through inverse modelling [12]. The inverse problem consists of finding a set of fluxes optimally matching available atmospheric observations and prior inventories within their respective uncertainties. It is solved using atmospheric tracer transport models [5].

A GHG measurement network started to be developed after Keeling [21] discovered the rising CO_2 concentrations in the late 1950's. Initially, remote islands and coastal sites were preferred for establishing measurement sites due to their distance from strongly variable sources that are resulting in a large temporal variability of trace substance mixing ratios that were at that time considered complicated to interpret. Tall towers started to be used as part of the GHG observational infrastructure in the 1990's. They allow to obtain atmospheric observations on the continent that are more representative for a larger region, as the placement of measurements in higher altitudes above ground minimizes the influence of very local fluxes on the observations [4, 13]. This also overcomes the problem of complicated airflow in the lowermost 100–200 m of the planetary boundary layer [29]. Tall tower measurements cannot be replaced by measurements on mountain tops as these stations are influenced mainly by air from the free troposphere [23] and thus provide only very limited information on GHG surface sources and sinks.

The area around the tall tower from which fluxes substantially contribute to the observed short-term variability of GHG mixing ratios (i.e. the variability occurring independently of the seasonal cycle and interannual trends) is called the footprint area [11]. Footprint areas vary with tall tower sampling heights. The footprint area of measurements at tall tower tops reaching into well-mixed portions of the planetary boundary layer is substantially larger than the footprint of measurements closer to the ground [32]. Measurement networks aim to combine footprint areas of several tall towers in order to cover a larger area, e.g. continent, in a homogeneous manner to avoid spatial gaps [15].

Long-term observations (20+ years) required to understand the present state and predict future behaviour of climate, carbon cycle and GHG emissions in Europe will be provided by ICOS (Integrated Carbon Observation System, http://www.icos-infrastructure.eu). ICOS purpose is to track carbon and other GHG fluxes in Europe and adjacent regions by monitoring ecosystems, the atmosphere and oceans through an integrated network. The ICOS preparatory phase (funded by the European Commission under the FP7) ended in 2013 and was joined by 17 European research institutions including the Czech Global Change Research Centre. ICOS is a part of the European Strategy Forum on Research Infrastructures (ESFRI). The improvement and extension of the European observation capacity for non-CO_2 greenhouse gases is targeted by InGOS (Integrated non-CO_2 Greenhouse gas Observing System, http://www.ingos-infrastructure.eu), an EU funded integrating activity project ending in October 2015.

The European tall tower network includes currently the following operating stations: Angus (232 m, Scotland; [19]), Trainou (200 m, France; [37]), Cabauw (213 m, The Netherlands; [32]), Ochsenkopf (163 m, Germany; [30]) and Bialystok (300 m, Poland; [28]). In the USA, measurements are also conducted on very tall towers (610 m in North Carolina and 447 m in Wisconsin; [4]). GHG fluxes in Russian Central Siberia are monitored by the Zotino tall tower (304 m, [34]). Except these mentioned tall towers, a number of smaller towers (< 150 m) are operating in Europe outside of ICOS (e.g. Hegyhátsál in Hungary, 117 m; [13]) and elsewhere. TV/radio broadcast masts are often used for GHG measurements (as is the case of the Angus, Trainou, Bialystok, Ochsenkopf and Hegyhátsál towers or the US very tall towers) in order to save costs for building expensive research infrastructures.

The Atmospheric Station (AS) Křešín u Pacova consists of a 250 m tall tower, and has been constructed in 2012–2013. It is part of the CzechGlobe project (operated by the Global Change Research Centre, Academy of Sciences of the Czech Republic) that aims towards the construction of a spatially distributed global change research infrastructure in the Czech Republic. The AS started operation in 2013 and has been assigned the function of the Czech National Monitoring Point focused on GHGs, air quality and meteorological parameters. The AS Křešín u Pacova, with its tall tower designed exclusively for scientific purposes and according to ICOS recommendations, will be a first class research infrastructure in Europe. Its main feature is the combination of measurements for several atmospheric programs (core partnership in ICOS; associated partnership in InGOS, GMOS, Global Mercury Observation System, www.gmos.eu, and ACTRIS, Aerosol, Clouds, and Trace Gases Research Infrastructure Network, http://www.actris.net), including GHG emissions, aerosols and reactive gases, which preludes the monitoring super-sites envisioned in the coming years. The AS is also located very close to other important monitoring and research infrastructures (the Košetice Observatory, ICOS Ecosystem Station and GEOMON [25] small forested watershed), together forming the Co-located Station Košetice – Křešín u Pacova.

6.1.2 Methods

6.1.2.1 AS location

The AS Křešín u Pacova is a central European background monitoring station located right next to other three research infrastructures. The Košetice Observatory is an air quality and meteorology monitoring infrastructure run since 1988 by the Czech Hydrometeorological Institute (CHMI). The ICOS Ecosystem station, established in April 2012, is operated by the Global Change Research Centre and monitors matter (GHG) and energy fluxes between the atmosphere and the local agro-ecosystem, using standard eddy covariance methodology (for further details see the chapter by Havránková et al. in this book). The small GEOMON forested watershed Anenský brook operated by the CHMI is a part of the Košetice Observatory and also ICP-IM (International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems, for further details see the chapter by Oulehle et al. in this book). It has been providing monitoring data from 1994 on.

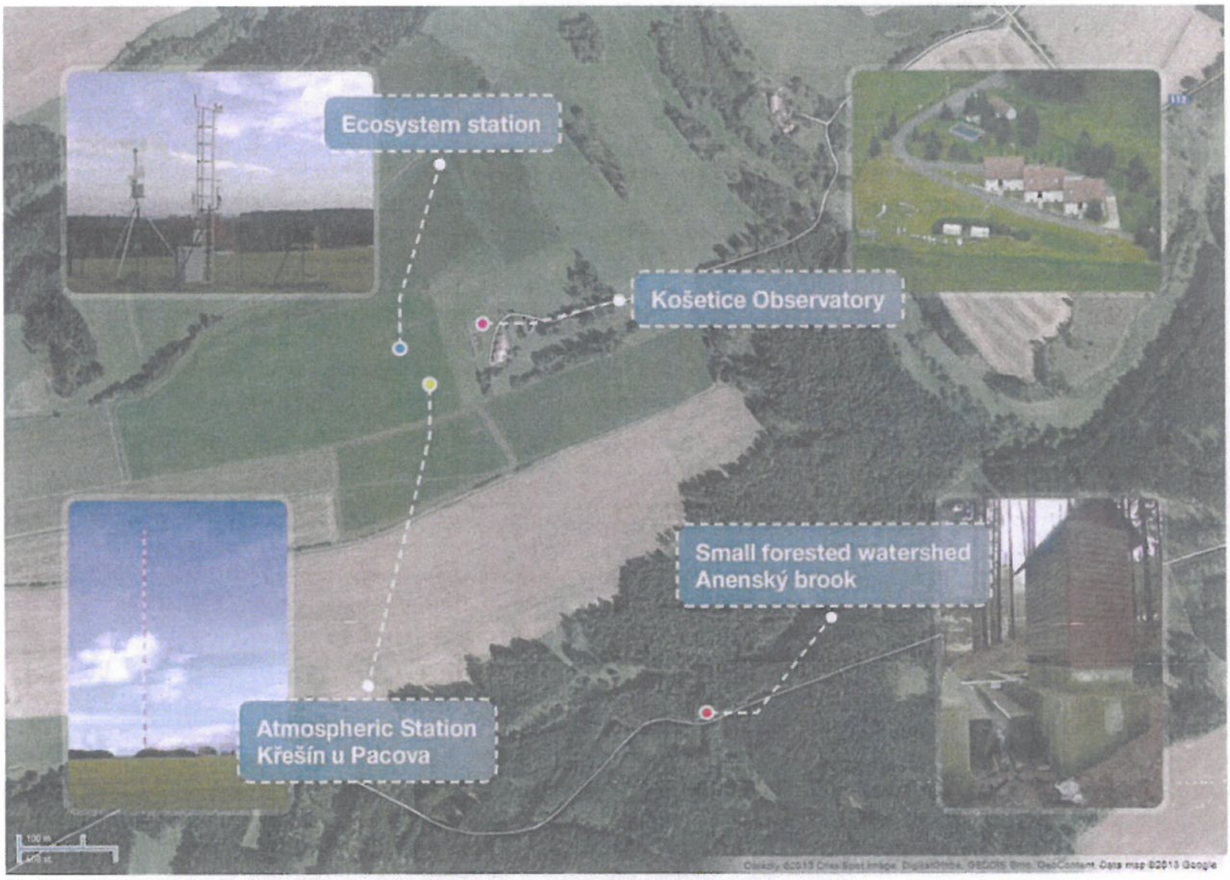

***Fig. 6.1–1.** Location of the four infrastructures forming together the co-located station Košetice – Křešín u Pacova.*

The character of the site as rural background located in densely populated central Europe, far (> 100 km) from major pollution sources (cities, industry), has been confirmed in numerous studies using air quality data from the Košetice Observatory (e.g. [8, 38]). Atmospheric long-range transport to the site may be expected especially from the west and northwest, comprising also marine air masses; as previously studied for persistent organic pollutants monitored at the Košetice Observatory by applying statistics to air mass backward trajectories generated in 500 m above ground starting heights [7]. An exact footprint analysis for the various tall tower sampling heights will be conducted in near future.

6.1.2.2 Measurements and sampling mode

The AS is designed to become an ICOS Level 1 station as it manages all the mandatory measurements for this kind of station. This in contrast to Level 2 stations, which operate only a subset of Level 1's mandatory parameters [15]. To fully exploit the AS infrastructure potential, selected air quality parameters were added to the measurement parameters list. This list may be extended in future, e.g. by an additional set of anemometers with high sampling frequency, accelerometers and strain gauges for wind engineering purposes (measurement of characteristics of the wind and response of the mast).

The current list of measurements contains: (i) concentrations of CO_2, CO, CH_4, N_2O, total gaseous mercury, tropospheric ozone and optical properties of atmospheric aerosols (continuously), (ii) elemental and organic carbon (EC/OC, semi-continuously), (iii) ^{13}C, ^{14}C and ^{18}O in CO_2, H_2, ^{222}radon, SF_6, O_2/N_2, CO_2, CO, CH_4, N_2O (episodically) and (iv) selected meteorological parameters and the boundary layer height. The vertical gradients of the monitored parameters are depicted in Fig. 6.1–2. The particular instrument identifications and short analysis/measurement principles are given in Table 6.1–1. The particular instruments were chosen according to the recommendations provided by ICOS, GMOS and ACTRIS.

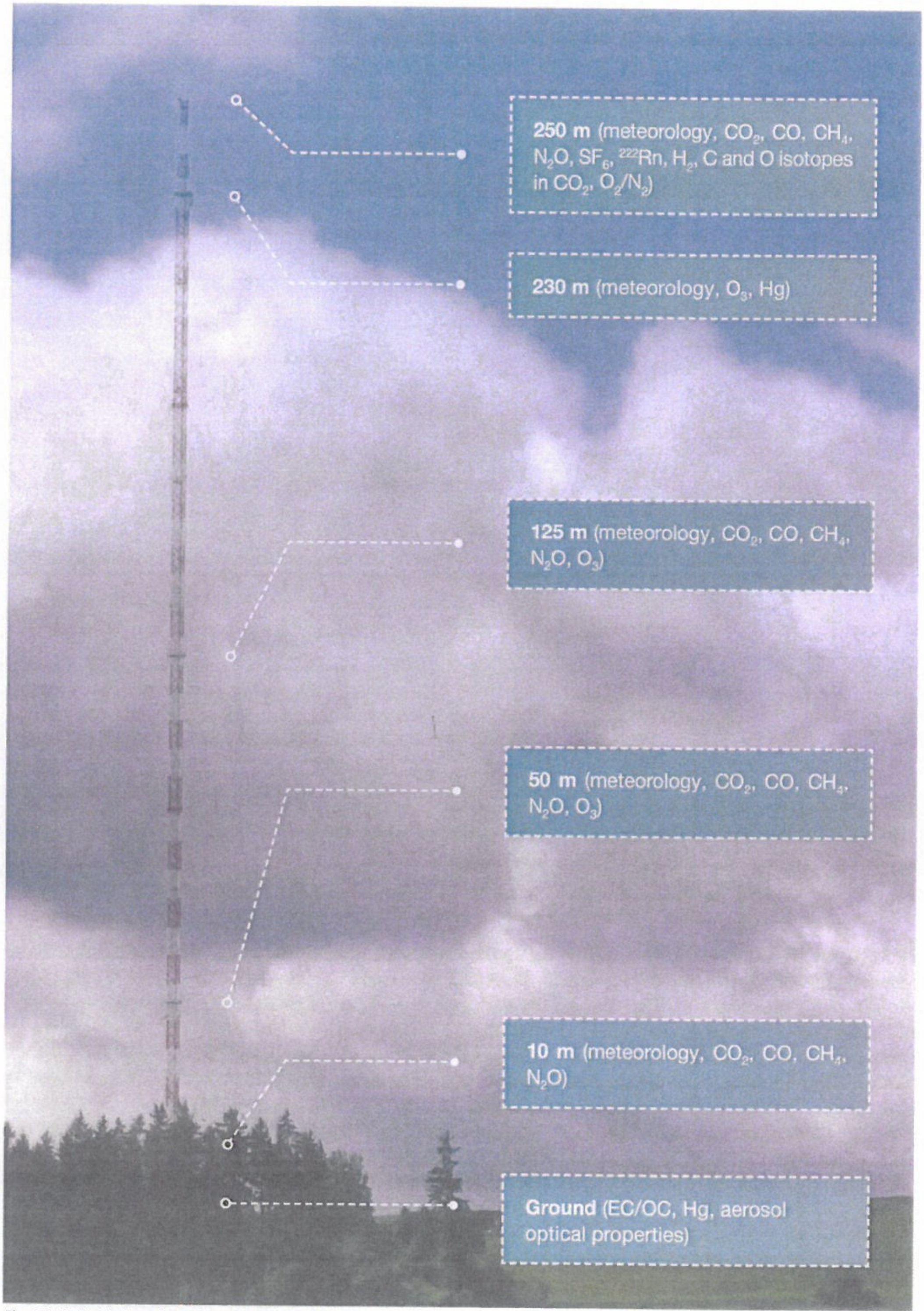

Fig. 6.1–2. Vertical gradient of monitored parameters.

Table 6.1–1. AS Křešín u Pacova instrument specification and short analysis principle description.

Parameter	Instrument	Measurement principle
CO_2, CH_4	Picarro G2301	IR cavity ring-down spectroscopy
CO, N_2O	LGR N2O/CO-23d analyser	IR cavity enhanced absorption spectroscopy
^{13}C, ^{14}C and ^{18}O in CO_2, ^{222}radon, H_2, N_2O, SF_6, O_2/N_2, CO_2, CH_4, CO, N_2O	Analyses in external laboratories	Mass spectrometry in various modifications
O_3	Thermo 49i	UV photometry
Hg	TEKRAN 2537B	Cold vapour atomic fluorescence spectroscopy with amalgamating preconcentration
EC/OC	Sunset – model 4G Semi Continuous Field Analyser	Pyrolysis and optical analysis (NDIR)
Aerosol light absorption	Aethalometer Magee Scientific AE31	Attenuation of light through a loaded filter
Aerosol light scattering	Nephelometer TSI 3563	Extinction of light over distance
Wind speed and direction	2D heated anemometer WindObserver 65	Ultrasonic anemometry
Air pressure	Barometer R. M. Young 61302	Barometer
Air temperature and relative humidity	Vaisala HMP155	Platinum temperature sensor, capacitance humidity sensor
UVA and UVB radiation	to be selected	Semiconductor photodetectors
Planetary boundary layer height	Vaisala Ceilometer CL51	LIDAR

6.1.2.3 AS measurement infrastructure

The AS itself consists of a 250 m tall guyed mast, a container for instrumentation situated at the base of the mast and another one at the height of 230 m on the mast body. The mast body is a lattice, triangular structure with a width of 2.6 m up to the 232.5 m height and a width of 1.5 m above 237.5 m. The mast is guyed at five levels into three directions with one strand guy ropes of 40 mm and 50 mm diameters with zinc-aluminium composite filled sockets at the ends. The ropes are anchored to concrete blocks through stretching devices enabling the application of the required stresses to the ropes. The forces were measured by strain gauges and additionally by hydraulic jacks. The mast is equipped with a hoist up to 228 m for up to 3 persons, ladder without cage with safety rail, 13 platforms and three galleries. Aircraft safety is ensured by red/white painting and obstruction lights.

Of the platforms situated in 10, 50, 125 and 230 m height levels the first three are occupied by air-conditioned outdoor racks containing ozone analysers, data loggers for meteorological sensors, data network and free space for eventual additional instrumentation. An air-conditioned technological container is situated at the 230 m level and contains mercury and ozone analysers, gas cylinders, data loggers for meteorological sensors, data network and free space for eventual additional instrumentation. A fourth air-conditioned outdoor rack positioned at 245 m contains data loggers for meteorological sensors and data network. The operation of the mast is ensured by an electric 230/400 V network with backup power supply.

The 3 × 6 m container at the mast base contains GHG analysers, a server ensuring the operation of the AS and data transfer, calibration gases, various sampling and safety equipment and electric connection for the mobile laboratory (Section 6.1.2.4.). Air samples for GHG determination are transported to the analysers in permanently flushed (flow rate 15 $l.min^{-1}$) lines (Synflex tubing 1300 1/2", sandwich PE and Al). The system is depicted in Fig. 6.1–3.

6.1.2.4 Analyses, quality control and assurance

ICOS related measurements have to be long-term, of the best precision currently available and compatible among individual network stations. In order to get homogeneous data, ICOS standardizes the equipment and protocol within its network. Because the ICOS network also aims to meet the WMO compatibility goal (GAW report n° 194), the deployed continuous gas analysers must be compliant to the performance requirements specified in Table 6.1–2 (for other instrument performance specifications see [15]). These specifications may be updated regularly by taking into account the performances of the best available instrument on the market.

Table 6.1–2. Continuous gas analyser performance required by ICOS (as of May 2013, [15]). Test conditions: dry air; room temperature: 20 °C ± 2 °C; room pressure: atmospheric pressure with a natural variation.

Component	Guaranteed specification range	Precision (1-σ)*	Reproducibility (1-σ)**
		1'/60' average raw data	10' average over a month
CO_2	300–500 ppm	< 50 ppb/25	< 50 ppb
CH_4	1500–2500 ppb	< 1 ppb/0.5	< 0.5 ppb
CO	30–1000 ppb	< 2 ppb/1 ppb	< 1 ppb

** Measuring a gas cylinder (filled with dry natural air) over 25 hours; first hour rejected (stabilization time).*
*** Measuring alternately a gas cylinder (filled with dry natural air) during 30 minutes and ambient air (not dried) during 270 minutes over 72 hours. Statistics based on the last 10 minute average data of each 30 minute cylinder gas injection (first 20 minutes rejected as stabilization time).*

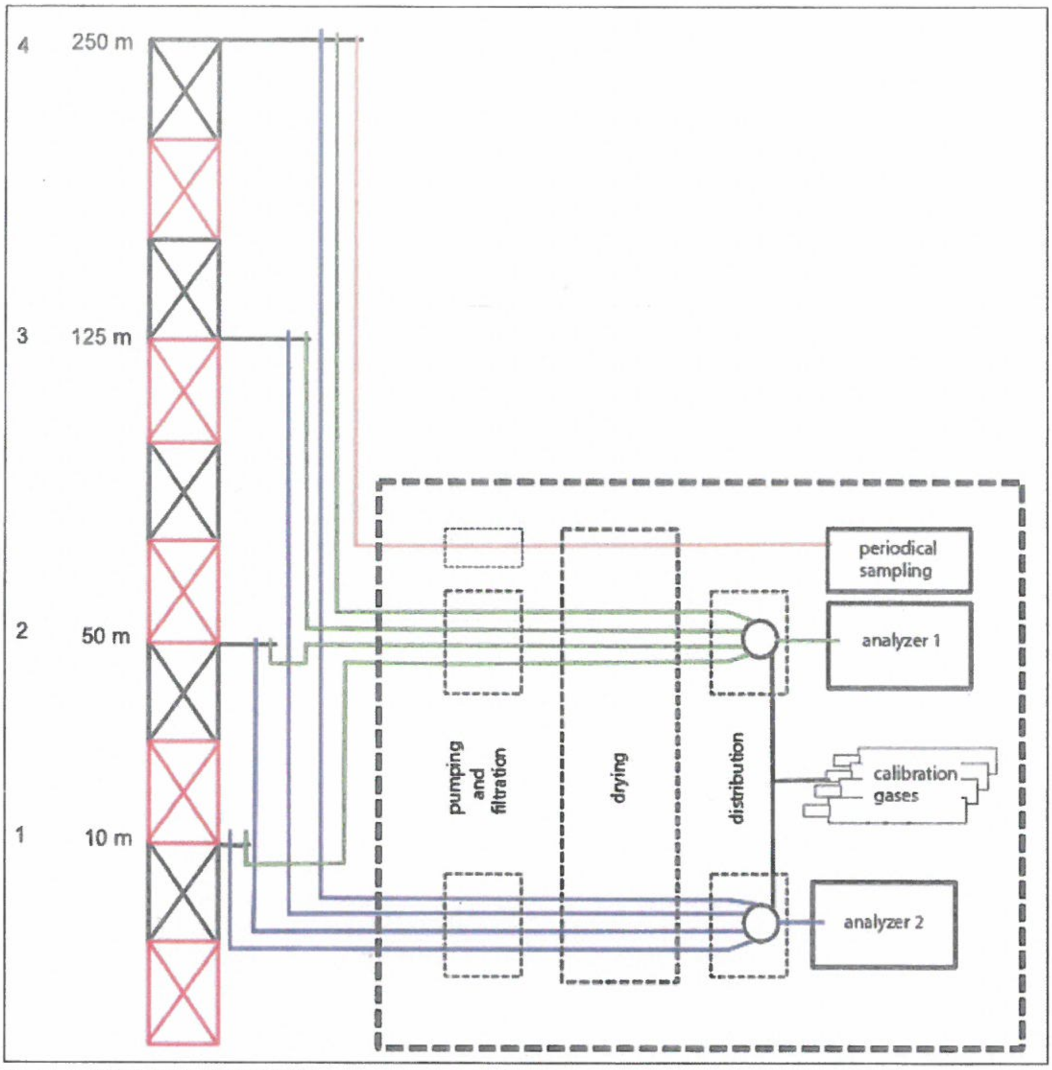

Fig. 6.1–3. Line scheme for GHG sampling.

Periodical air flask sampling allows for additional parameter measurements which are not performed continuously and also for quality control of the in-situ continuous analysis. Principal investigators (PIs) of the measurement sites are responsible for the first order quality assurance and control (QA/QC). This is complemented by a QA/QC plan defined by the ICOS Atmospheric Thematic Centre (ATC, for full description see [15]). In order to limit the risk of a systematic bias within its standardized network, ICOS will perform additional periodic measurements with a different and independent technique (QC mobile laboratory) and flask sampling. ICOS will be also involved in international intercomparison programs.

The best calibration strategy adapted to the AS setup is defined after an initial test period. Depending on the initial test results, the calibration strategy must be then adjusted (with ATC support) and respect the minimum ICOS calibration requirement [15]. The ICOS Central Analytical Laboratory will provide the following services to the atmospheric network: (a) provision of calibrated standard gases in high-pressure cylinders, (b) analysis of ICOS parameters for periodical sampling and (c) supply of samplers for $^{14}CO_2$ analysis.

The ICOS meteorological sensor selection is based on the WMO recommendation specified in the WMO Guide N° 8. As ICOS does not aspire to be part of a meteorological station network, its measurement uncertainty requirements are based on the more affordable uncertainty specified by the WMO [15]. The sensors must be calibrated according to the periodicity specified in [15] or the manufacturer recommendation if more stringent and justified.

The TEKRAN 2537B instrument is suitable for long-term atmospheric background monitoring, because it is capable of precise and accurate total gaseous mercury determination in ambient air at levels lower than 0.1 $ng.m^{-3}$. The EC/OC analyser SUNSET G4 and similar analysers are used in international monitoring networks (ACTRIS) and programmes (European Monitoring and Evaluation Programme, EMEP and Global Atmosphere Watch, GAW), thus fulfilling their requirements.

Measurements of atmospheric aerosol optical properties are carried out according to the recommendations of the ACTRIS network standardizations ([2], [3] for aerosol light scattering measurements and [35], for aerosol light absorption measurement), including corrections of the aerosol light scattering coefficient and calculation of the aerosol light absorption coefficient. ACTRIS recommendations on instrument maintenance and sampling conditions are followed as well. For example, a strict restriction of relative humidity in the air flow containing sampled aerosols is applied, in order to ensure data comparability within the ACTRIS network. Similar requirements are maintained on the aerosol number size distribution measurements, thus the datasets are appropriately measured under the same conditions. This will allow to look for connections between the two datasets.

6.1.2.5 Data handling and policy

ICOS targets high quality data which involves both high precision measurement and stringent data quality management procedure (including data check and validation). Data sent to the ATC will be automatically processed and archived in a database. The processing depends on the type of instrument, i.e. the continuous gas analyser data are to be corrected, whereas there is currently no QA procedure foreseen of meteorological data. All the processing steps are traced. The ATC data analysis will implement systematic comparison of linear/quadratic fits and prepare data products for calibration optimization. The ATC offers an application to station PIs in order to allow them to manually validate their data. Using a secured encrypted connection to the ATC data server, the PIs have direct access to their data and can manually reject invalid, contaminated or outlier measurements.

The ICOS data center from where data and ancillary data sets will be published and accessible for the user is called the Carbon Portal. The Portal is responsible for handling and providing ICOS data products. The ICOS data policy guarantees a smooth data flow from the research infrastructure national networks, central facilities and Carbon Portal to the users to provide an open, easy access to ICOS data and develop user-driven services for user communities (e.g. to scientists, national and international agencies, local authorities, general public). It respects the European legal framework related to environmental data, information and databases as well as relevant international observation system initiatives, e.g. GEOSS [16].

The aerosol data (EC/OC, optical properties) will be regularly reported to the ACTRIS datacentre EBAS, operated by NILU (Norwegian Institute for Atmosphere Research). The data will be automatically resubmitted to the EMEP database, which is also a part of EBAS. There is an on-line mercury data flow to the Air Quality Information System, operated by CHMI. The total gaseous mercury and tropospheric ozone measurement data will be regularly sent to the GMOS and EMEP international datacentres.

6.1.3 Research activities

6.1.3.1 Greenhouse gases

The AS will contribute to the following scientific goals defined under ICOS: (a) long-term measurement of GHG concentrations and their exchange dynamics, (b) provision of long-term observations required to understand the present state and predict future behaviour of the global carbon cycle and GHG emissions and (c) monitoring and assessment of the effectiveness of carbon sequestration and/or GHG emission reduction activities on global atmospheric composition levels, including the attribution of sources and sinks by region and sector.

Two particular goals are set for the investigation of GHG's using the AS infrastructure. The scientific characterization of the AS infrastructure will be conducted by finalizing and testing the AS sampling design, calculating the tall tower footprint [11] and describing the local planetary boundary layer dynamics [29]. Further, the GHG variability at different time scales measured at the AS will be studied. In the processes responsible for such variability, those associated with surface emissions, and those related to atmospheric transport will be identified and quantified. GHG levels will also be studied by chemical transport modelling [27]. The comparison of measurements with simulated data will provide a tool to better understand the spatial representativeness of the AS Křešín u Pacova observations.

The planned studies will benefit especially from the possibility to analyse correlations between GHGs and other trace gases or aerosols monitored at the AS Křešín u Pacova. The GHGs variations will be also analysed with respect to the local meteorology and air mass trajectories to identify the signature of the different regions to the signals observed at the tall tower. Quantitative estimates of GHG emissions can be done by using ^{222}Rn and planetary boundary layer height data [24, 36].

6.1.3.2 Aerosol optical properties

The influence of solar radiation on the global climate is well described and discussed. However, aerosols continue to contribute the largest uncertainty to the total radiative forcing estimate [18]. The most important properties of atmospheric aerosol connected to the direct effect on the radiation balance are the optical characteristics, mainly the extinction coefficient. The extinction coefficient, the sum of absorption and scattering coefficients, describes the amount of radiation absorbed and/or reflected, considerably changing the overall radiative balance. Recently, a substantial increase in the interest in the influence of anthropogenic aerosols on the climate can be recorded.

The following goals are set for the investigation of aerosol optical properties using the AS infrastructure: (a) long-term measurements of aerosol light scattering coefficient, (b) long-term measurements of aerosol light absorption coefficient, (c) assessment of aerosol light extinction coefficient, (d) evaluation of changes in the aerosol optical properties in time, depending on season of the year, month, day of week etc. and (e) description of connection between various aerosol size fractions and its optical properties.

The study design is unique thanks to especially: (a) so far the only measurements of solar radiation absorption and scattering on atmospheric aerosols in the Czech Republic and (b) the connection of the measurements of atmospheric aerosol optical properties with additional measurements (particle number size distribution, chemical composition), this will provide a complete picture of aerosol properties.

6.1.3.3 Selected atmospheric pollutants

Anthropogenic sources have enriched the atmospheric mercury reservoir and associated deposition to terrestrial and aquatic ecosystems by approximately three times compared to pre-industrial levels ([1] and references therein). Comparisons of tropospheric ozone background levels with those measured over a century ago indicate that current levels have increased by approximately two times [33]. Both mercury and tropospheric ozone cause adverse effects on human health and ecosystems [6, 9] perhaps also at current background environmental levels [14]. Both mercury and ozone (together with particulate matter and persistent organic pollutants) are classified as atmospheric pollutants with a high potential for regional, intercontinental and hemispheric transport [20, 31].

The following goals are set for the investigation of atmospheric pollutants using the AS infrastructure: (a) determination of basic patterns and variations of total gaseous atmospheric mercury and tropospheric ozone concentrations, representative for the central European background, including the description of vertical concentration gradients under certain conditions [10], (b) investigation of the pollutants long-range atmospheric transport patterns and episodes of elevated concentrations and (c) investigating the impacts of climate change on air quality and long-range transport of air pollution (i.e. the long-term temporal and spatial stability of determined potential source areas influencing background measurements; [22]).

The study design is unique thanks to especially: (a) the automatized mercury measurement producing time series of high-frequency concentration data of total gaseous mercury will be the only in the Czech Republic, (b) the parallel automatized measurements up to 230 m above ground, coupled with air mass back trajectory statistics, comprise a unique setting not only in the Czech Republic, but also worldwide and (c) future climate projections will be considered especially with emphasis on high resolution simulations performed in the frame of EURO-CORDEX (http://www.euro-cordex.net) which aims at providing climate projections over wider European area at a spatial resolution of up to 10 km.

6.1.3.4 Tall tower construction, statics and dynamics

The tall tower is suitable for research of wind and structure engineering purposes. The research of wind characteristics is important for the design and assessment of the tall slender structures that are currently being planned. Measurements and investigations will be focused on wind turbulence characteristics, in particular power spectral densities of wind velocity, and the coherence function of turbulence or turbulent length scales. Wind velocities and characteristics will be measured concurrently with the response of the tower structure. The static and dynamic behaviour of the structure under wind loading will comprise the second important part of this research.

6.1.3.5 Challenges

The AS Křešín u Pacova provides a unique research opportunity and challenge due to (a) a broad spectra of monitored chemical species, meteorological and other parameters, (b) provision of large datasets suitable for conducting multidisciplinary research activities, (c) its vicinity to other three important research infrastructures forming together the Co-located station Košetice – Křešín u Pacova and (d) participation in a number of international programs and projects (ICOS, InGOS, GMOS and ACTRIS), also ensuring access to datasets from other monitoring sites necessary for conducting joint multi-site studies.

6.1.4 Conclusions

The manifold AS research infrastructure supports and claims for a multidisciplinary research approach. Further activities connected to the AS comprise education of students as well as the dissemination towards the general public. The AS Křešín u Pacova is an open access research infrastructure. It can be used by external users under clearly defined and transparent conditions. The infrastructure may be also used under certain conditions by the private sector (e.g. communication and wind energy companies). Currently, cooperation with the following subjects is under way or considered:

- Institutes of the Academy of Sciences (Institute of Computer Science, Institute of Scientific Instruments, Institute of Chemical Process Fundamentals, Institute of Theoretical and Applied Mechanics, Nuclear Physics Institute)
- Universities (University in Pardubice, Masaryk University, Brno University of Technology, University of Defence)
- Government institutions (Czech Hydrometeorological Institute)
- International research and monitoring organizations (Laboratoire des Sciences du Climat et de l'Environment – France, Meteorological Synthesizing Centre East – Russia, University Wageningen – Netherlands, Deutscher Wetterdienst – Germany)
- Private sector (EXCON a.s., internet operators)
- Locals (cooperation with local and regional governments, excursions, open disputations)

The Global Change Research Centre welcomes proposals for further research and monitoring activities in the mentioned (Section 6.1.3) or other research areas. Especially proposals for common research projects are welcome. The AS research activities are significantly supported by international cooperations and access to data from the ICOS, InGOS, ACTRIS and GMOS networks as well as the adjacent research infrastructures from the Co-located Station Košetice – Křešín u Pacova.

6.1.5 Acknowledgement

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