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Hans Puxbaum & Wilfried Winiwarter (Eds.)

Advances of Atmospheric Aerosol Research in Austria

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Advances of Atmospheric Aerosol Research in Austria

Edited by
Hans Puxbaum & Wilfried Winiwarter

Series Editors
Viktor Bruckman, Ernst Bruckmüller, Martin H. Gerzabek,
Gerhard Glatzel, Marianne Popp & Verena Winiwarter

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Vorwort

Ersetzt man in der Vier-Elemente-Lehre der antiken griechischen Philosophie (Feuer, Wasser, Luft, Erde) den Begriff "Feuer" durch "Energie", so hat man eine gute Aufzählung jener Problemfelder, die für die Existenz künftiger Generationen entscheidend sein werden. Während es bezüglich der stetigen Erhöhung des CO₂-Gehaltes und der damit verbundenen Erderwärmung noch "Klimaskeptiker" gibt, die die Verursachung durch den Menschen in Frage stellen, steht es bei der Feinstaubbelastung der Luft außer Frage, dass diese durch menschliche Aktivitäten stark gesteigert wird, wobei die Anteile von Industrie, Verkehr und Hausbrand durch geeignete Analysen gut nachzuweisen sind. Doch trotz dieser gesicherten Datenlage sind Maßnahmen, die ohne Zweifel zu Verbesserungen führen würden (Geschwindigkeitsbeschränkungen, Auflagen für die Verbrennung von Biomasse, Rauchverbote ...) kaum implementierbar.

Es ist daher ein interdisziplinärer Ansatz notwendig, der die Problematik umfassend betrachtet und auf diese Weise auf ihre Dringlichkeit hinweist. Nur so werden sich Maßnahmen durchsetzen lassen, die entsprechende Änderungen des Lebensstils herbeiführen und auch kommenden Generationen ein "lebenswertes Leben" auf diesem Erdball ermöglichen werden.

Ein Kernproblem hat der frühere Obmann der Kommission für Reinhaltung der Luft, Prof. Dr. Othmar Preining, so treffend mit folgenden Worten beschrieben: "Wir leiden an einem Übermaß an Mobilität" – eine Aussage die sich auch auf andere Ursachen des atmosphärischen Feinstaubes erweitern ließe.

Die Interaktion von medizinischen, technisch-naturwissenschaftlichen und systemanalytischen Ansätzen, die im vorliegenden Band zur Aufklärung umweltrelevanter Fragestellungen beitragen, ist ein gelebtes Beispiel interdisziplinärer Wissenschaft. Die Kommissionen für Interdisziplinäre Ökologische Studien und für Reinhaltung der Luft der Österreichischen Akademie der Wissenschaften möchten mit der Serie "Interdisziplinäre Perspektiven" beitragen, im interdisziplinären Dialog wichtige Probleme der Gesellschaft zu diskutieren und innovative Ansätze zu fördern.

Wien, im Oktober 2012

Die Serienherausgeber:
Viktor Bruckman, Ernst Bruckmüller, Martin Gerzabek,
Gerhard Glatzel, Marianne Popp and Verena Winiwarter

Foreword

Applying the Aristotelian four elements ("fire", "water", "air", "earth") to current-day problems, one merely needs to replace the term "fire" by "energy" to describe the decisive issues for the existence of future generations. While there are still "skeptics" spreading doubt on the continuous increase of the atmospheric CO₂ concentrations and its relation to global warming, no such doubts exist on the significant human contributions to adverse atmospheric concentrations of particulate matter. Appropriate methods exist to quantify with high confidence the respective impacts of industry, traffic and household combustion sources. Despite of the generally well-described associations, measures which would improve an adverse situation (speed limits, constraints to biomass burning, smoking bans ...) can hardly be put in practice.

For this reason an interdisciplinary approach is needed to comprehensively cover this topic and thus to clearly demonstrate its importance. Only this way will allow measures to be adopted that lead to a change of lifestyle allowing future generations a livable life on this earth.

A fundamental problem has been described to the point by the late chairman of the Clean Air Commission, Prof. Dr. Othmar Preining: "We suffer from an excess of mobility". This statement one may easily extrapolate to other causes of particulate matter in the atmosphere.

The interaction of approaches used in medicine, in science and technology and in systems analysis as demonstrated in this volume is a living example of interdisciplinary science. The Commission for Interdisciplinary Ecological Studies and the Clean Air Commission of the Austrian Academy of Sciences intend to use their series "Interdisciplinary Perspectives" for contributions to the interdisciplinary dialogue urgently needed to cover important societal problems and to foster innovative ways of problem solving.

Vienna, in October 2012

The series editors:
Viktor Bruckman, Ernst Bruckmüller, Martin Gerzabek,
Gerhard Glatzel, Marianne Popp and Verena Winiwarter

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Introduction

Atmospheric aerosol research has a long tradition in Austria. From instrumental development to measurements and to health impact studies, Austrian researchers contributed to the development of the science. Milestones of the early work are described in the volume "History of Aerosol Science" by Preining and Davis (2000). Since then, the highly recognized work continued. This compendium illustrates the scientific progress performed at Austrian research institutions and field sites during the past decade.

Atmospheric aerosol research in Austria never developed as the domain of any individual institution. Instead, several groups have been very active in pursuing innovative and internationally renowned science in this field, forming a well-established network, which together provide a coherent total of a "virtual institute of aerosol science". The Clean Air Commission (Kommission für Reinhaltung der Luft, KRL) of the Austrian Academy of Sciences served as a focal point and as a panel for stimulating atmospheric aerosol research. The key achievement of the KRL was its support of the interdisciplinary cooperation among scientists from the different fields of aerosol research. This included scientists in aerosol physics, aerosol chemistry, epidemiology, forestry and agriculture, ecology, environmental technology, meteorology, as well as applied air pollution research. The support of the KRL helped bring together and coordinate research activities. While lacking the focus of a single institution, this way of implementation more than made up for it by allowing and inspiring collaboration across disciplinary boundaries.

The role of the KRL as a platform for scientific exchange has also been used to compile this overview. While KRL members formed the core of the team of authors, the coverage of this work extends beyond and also describes relevant work performed in Austria in general, providing an overview on activities representing more than 270 scientific papers cited involving one or more authors in Austrian affiliations. Thus the compendium is proof of the competence and complementarity of the research performed and its significant international impact.

The volume starts out with an overview on assessing the release of aerosols to the atmosphere in general (Winiwarter, pp. 4 ff) and continues describing approaches for emission abatement (Höflinger, pp. 16 ff) based on theoretic foundations, specific for "fugitive" dust sources. The next chapters deal with methodological development of measuring aerosols, first of all regarding the distinct physical parameters (Hitzenberger, pp. 24 ff) but also concerning optical and chemical characteristics (Hitzenberger and Bauer, pp. 32 ff) followed by the distinctive properties of bioaerosols (Bauer, pp. 47 ff).

Two sections present efforts to unravel specific atmospheric processes associated with aerosol – its scavenging behaviour (Kasper-Giebl, pp. 58 ff) and its response to air mass changes (Berner and Hitzemberger, pp. 65 ff). The latter also is an example of research on aerosol climatology. Model results on aerosol transport and dispersion along wind fields and resulting assignments of PM load shares to source sectors are presented by Sturm et al. (pp. 68 ff) while Puxbaum (pp. 85 ff) concludes from atmospheric measurements to the sources directly via source apportionment.

The next papers focus on health effects. Neuberger (pp. 103 ff) describes studies that link aerosol exposure and human health impacts (epidemiology), while Haluza (pp. 116 ff) reviews the Austrian toxicological studies. Integrating health effects, atmospheric dispersion and formation with emission and emission abatement modelling into a single policy tool is performed in integrated assessment modelling (Amann, pp. 121 ff). At a global application also climate effects of aerosols are considered. Finally, an overview of a major overarching study is presented, the internationally acclaimed AUPHEP project performed under KRL's coordination, which demonstrated the level of interdisciplinary working collaboration achieved (Hauck, pp. 130 ff). An outlook containing aspects for future research potentials and needs (Winiwarter, pp. 136 ff) concludes this compendium.

The overall scheme in this volume thus covers, for aerosols, the entire fate of trace compounds in the atmosphere, from their release in form of emissions via dispersion and transformation towards removal processes. Furthermore it includes the response of substrates, specifically regarding human health. While the respective processes characterize the change of atmospheric conditions, exactly the conditions in form of atmospheric concentrations can be observed directly. Some of the processes (emissions) can be influenced by humans and thus are responsive to policy actions, others are given naturally (specifically the dispersion processes) nevertheless decisively influence the impacts in combination and simultaneously.

For this reason, emissions and ambient air concentrations need to be assessed independently to describe an air quality situation. An adequate description has been provided in terms of a budget considerations and a budget approach, on global scale, in a separate activity of the KRL. The respective contribution on aerosol budgets has been outlined by Jaenicke (2005). The fact that this work derived from a KRL sponsored activity again points to their central role in the Austrian aerosol science.

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Inventorying PM emissions

Wilfried Winiwarter

with contributions by Hans Puxbaum

1. Introduction

Transfer of material into the atmosphere is a key factor influencing atmospheric concentrations of trace constituents. Emission inventories provide the information needed to understand and quantify the involved processes. Both regulatory interests and scientific needs require high quality emission data. In contrast to inventories of gaseous pollutants, which are well-established, inventories of particulate matter (PM) suffer from inadequate reliability. While considerable efforts for improvements are under way, the major obstacles are in the specific properties of PM. PM is not a unique substance, but an internal and/or external mixture of a multitude of compounds from very different origin, different effects on substrates, and different size. Quantification of emission rates is hampered by the large number of distinct natural and anthropogenic, direct and fugitive sources, as well as their strong dependencies on measuring conditions (temperature, lapse time) and process state (start-up vs. equilibrium). Efforts in Austria resulted in some of the first nation-wide inventories in Europe, which to a considerable extent were supported by country-specific information on emission patterns.

2. Method to set up emission inventories

Emission inventories compile the information for many different sources. For most sources, emissions are calculated as the product of an activity (describing the extent at which an activity occurs) and an emission factor representing the intensity of emissions. It is common practice to rely on existing guidelines which provide recommendations of potentially important source sectors. Following these recommendations first of all allows comparability to similar activities in other areas. Moreover, it safeguards applicability of the emission factors suggested in these guidelines.

For Austria, a first PM inventory was established in 2001 (Winiwarter et al. 2001, 2002). A revision focussing on the open topics as identified in the first study was prepared in a second assessment (Winiwarter et al. 2007, 2008) which also took advantage of the developments made in the scientific literature since, especially with regard to fugitive emissions. A sizable set of specific emission-relevant information could be obtained from measurements obtained in Austria. In the following, we will detail the methods used by source sec-

tor, with consideration of fugitive sources (very low emission rates over a large area provide sizable contributions to the total) vs. combustion sources which in general are released via an exhaust duct (stack, chimney, exhaust pipe).

Combustion in industry and power plants

For large installations, direct source measurements are available. Due to the high efficiency and large degree of implementation of abatement devices like electrostatic precipitators, overall emissions are small even for large point sources operated on solid fuels.

Industry (fugitive emissions)

Fugitive emissions from industry derive from fractionating processes and/or mechanical handling of "dusty" material which leaves it airborne. The handling steps (loading / dropping / moving operations) are quite well understood and listed in VDI methods. Theoretical considerations allow developing abatement strategies for fugitive dust emissions (see this compendium, pp. 16 ff).

Very little information is available on construction (e.g., demolishing of buildings) or quarries. The sheer amount of material extracted in quarries in Austria makes this a source to be considered, irrespectively of the actual release rate applied.

Domestic heating

Traditionally, woody biomass is often used for space heating in Austria, especially in the forested areas of the country. Since about 1995, highly efficient stoves are on the market and being installed in houses. It is now estimated that more than 30% of the biomass is burnt efficiently at low emission rates in such new stoves. Particle emission factors of the older types of Austrian stoves are available from measurements on in-use stoves performed 1997/98 (Spitzer et al. 1998) as well as from new stoves (Obernberger and Brunner 2005).

Table 1 presents details on sets of focused Austrian source measurements. The detailed chemical composition of particles emitted from combustion of logwood in a tile stove (Schmidl et al. 2008a) were performed with the major wood types of Austria. These data do not yield emission rates, but allow improved interpretation of ambient air data with respect to source apportionment. In a similar way the smoke of the combustion of garden leaves was chemically characterised (Schmidl et al. 2008b). Recently emission tests of PM₁₀ from modern stoves (pellet stoves and "chimney type" logwood stoves) were per-

med including detailed chemical composition (Schmidl et al. 2011, Kistler et al. 2012).

Table 1: Emission factors derived from stove measurements (PM emission determined after a dilution step, except where marked).

	PM10 (mg/MJ)
*) Austrian test 1997/98 logwood stoves (Spitzer et al. 1998)	148
*) Austrian standard 1998 for logwood stoves (Beech wood/standardised)	60
2 "Chimney stoves" 6kW, 10 kW,	83
3 Austrian wood types+Briquetts (Schmidl et al. 2011)	
"6 kW Chimney stove"	67
12 Central Europ. wood types+Briquetts (Kistler et al. 2012)	
"6 kW Chimney stove"	114
4 Portugese wood types (Gonçalves et al. 2010)	
2 Pellet stoves / wood pellets (Schmidl et al. 2011)	
"fullload"	8-11
"start up"	8-34
"maloperation"	3-21
Pellet stove (Schmidl et al. 2011)	
miscanthus pellets	8
triticale pellets	120
6kW Pellet stove / wood pellets (Kistler et al. 2012)	21

* PM determination from the undiluted "hot" exhaust stream.

Schmidl et al. (2011) compared emissions from two pellet stoves and two logwood fired "chimney" stoves. While the main components of the particulate emissions of "chimney" stoves are organic material and soot, the emissions of pellet stoves comprise predominantly inorganic ions (sodium, potassium, magnesium, calcium, chloride, nitrate and sulfate). These authors also investigated the emission behaviour of "new types" of agricultural biofuels, such as pellets from elephant grass (miscanthus), and triticale pellets, a type of "energy corn". While elephant grass pellets emissions of PM10 were even lower than for wood pellets, triticale pellets were "high emitters", with a factor of 9 higher PM10 emissions than from wood pellets.

Kistler et al. (2012) used different wood types from Alpine Central Europe and Central European plains on the same pellet and "chimney" stoves. While the Central Alpine forests are dominated by Spruce and Beech, with common occurrence (>5% of the forest area) of Fir, Larch, and Mountain Pines (Scots Pine, Black Pine), the forests in the Pannonian plain are dominated by Black

Locust, Hornbeam, several Oak types and Pines. Surprisingly large differences in the emission behaviour of PM₁₀ for different wood types were observed. This indicates that it may be necessary for the emission inventories to consider the different emission behaviour for different countries of Europe. E.g. Sessile Oak turned out to be a "high" emitter of PM₁₀, with a ten times higher emission rate compared to the "low emitters" Poplar and Larch. Similarly, in a joint study of the University of Aveiro (Portugal) and the TU Vienna, large emission differences of PM₁₀ were obtained for the four major wood types with common occurrence in Portugal: Eucalyptus, Cork Oak, Acacia ("Golden Wattle") and Maritime Pine.

Kistler et al. (2012) report odour emissions in addition to the PM₁₀ emissions, which can be used in dispersion models to estimate the impact of odour nuisance from wood combustion. The authors conclude that frequent short term occurrence of wood smoke odour is likely for many communities with traditional wood stove use ("wood burning communities").

As has been shown in US (Ward et al. 2006) and Scandinavian studies before, extensive use of fuel wood in "wood burning communities" may lead to violations of PM_{2.5} or benzo(a)pyrene (BaP) ambient air quality standards also in Austria. Exceeding the EU BaP target value due to wood smoke impact is evident in Zederhaus, Salzburg (Spangl and Nagl 2010). Thus, the information about the chemical composition of wood smoke from different wood types and stoves is also important for inventorying the emissions of the substances regulated by ambient air quality legislation (PM₁₀, PM_{2.5}; Pb, Cd, As, Ni; BaP) and for the components under the ECE reporting commitments (e.g. selected PAH and other POP's).

Road transport

Probably the best investigated PM source in general is the road transport. Emission factors for exhaust gases are available from a multitude of dynamometric test bench experiments. Here the main problem is to obtain reliable measurement results that also hold for interpretation in the real atmosphere – particles leaving the exhaust pipe are extremely small and still in the process of growth, as surrounded with high concentrations of condensable gases. The nationally characteristic high share of diesel cars adds to the importance of this source category.

Emission rates from automotive traffic are assessed for individual vehicles on dynamometer test facilities. Such investigations are performed in Austria at TU Graz and TU Vienna. The data are used for the official emission inventory of automotive traffic, the "handbook of Traffic emissions", edited for the countries Austria, Germany and Switzerland, in the current version HBEFA Version 3.1 including all EURO emission classes including EURO 5 and EURO 6,

and the chemical components HC, CO, NO_x, PM, CO₂, CH₄, NMHC, Pb, SO₂, N₂O, NH₃, and Benzene, as well as "primary NO₂", particle numbers and PM mass of passenger cars.

As some parameters are uncertain or difficult to access from dynamometer studies (e.g. the influence of malfunctioning cars, so called "super emitters", the "primary NO₂ emission" and non-exhaust PM emissions from abrasion and re-suspension) validation tests of the HBEFA emission rates are performed from on road measurements in tunnels or on streets and highways. Such "real world" tests have been performed in Styria, Carinthia and Salzburg by teams from TU Graz, TU Vienna and the local environmental authorities (Hausberger et al. 2003). Scientific evaluations were also reported for the Tauerntunnel, where three tests took place within three decades. The results of the first two tests demonstrate the decadal improvement of traffic emissions (Schmid et al. 2001), and a relatively good agreement between measured and modelled emissions (unpublished data). Non-exhaust emissions were investigated in two studies in the Kaisermuehlentunnel (a city highway tunnel), yielding different results in the two runs considered to reflect different driving conditions and different silt loadings of the highway surface (Laschober et al. 2004, Handler et al. 2008).

At the time of the first Austrian inventory (Winiwarter et al. 2001) available information on fugitive emissions from road transport (due to suspension of road dust, brake wear or tyre wear) was very unreliable. Since that time, measurements have been performed, some of which also cover activities in Austria (Ketzel et al. 2007). These measurements now indicate fugitive emissions to be about as important as exhaust emissions in terms of PM₁₀ mass.

Off-road transport

Emission factors for exhaust emissions are available, which are characterized by the typically low turnover in off-road vehicles. Engines tend to be old, new standards are implemented into the fleet very slowly. Very little information is available on fugitive emissions. This is a potentially important source which requires further efforts to be spent.

Agriculture

Indoor air in animal houses is known to be loaded with particulate matter. Simple extrapolation of air exchange rate would indicate this to be a considerable source, but the respective biogenic material can not be observed in the ambient air. Here again more information is urgently needed. Emission estimates due to agricultural field operations (plowing and packing, harrowing, disking, cultivating) are based on (few) European measurements, again with

Austrian participation (Öttl and Funk 2007, Funk et al. 2008). These studies differentiate strongly different emissions, with huge increases observed when soil is completely dry. The distinction between soil dryness seems to be a guiding parameter to establish an inventory.

Natural emissions

Except for wind-blown dust, which never was explicitly investigated in Austria, the most important natural source in terms of PM mass seems to be the release of fungal spores. A handful of ambient air measurements in the Vienna area indicate concentrations of fungal spores to be clearly larger than those of cellulose (marker compound for plant debris, which we regard to be likewise stable in the atmosphere). Several data series over Europe allow to compare ambient air winter and summertime ratios of cellulose to a few anthropogenic PM species. Assuming that emission ratios should match concentration ratios, we are able to provide an emission range for plant debris, and extending the same logics also the emission range for fungal spores. Adding these species provides a first quantification of Primary Biogenic Aerosol Particles (PBAP) emissions (Winiwarter et al. 2009a, Puxbaum et al. 2009). While this species provides about 5% (annual average) of the ambient PM₁₀ observed, it is also important as natural cloud condensation nuclei or compound affecting the atmosphere's radiative properties.

Following an event of volcanic dust impacts, a very recent study with Austrian participation estimated emission strengths of emissions from the Icelandic volcano Eyjafjallajökull. Stohl et al. (2011) apply an inversion model to satellite observations of aerosol to arrive at total emission of airborne particles due to this volcanic eruption in the year 2010 over 40 days of 8.3 ± 4.2 Tg, which is the same order of magnitude as the total annual anthropogenic PM₁₀ emissions over Europe of 6 Tg (see Winiwarter et al. 2009a).

3. Some key results of Austrian emission inventories

Describing source sectors individually allows to identify a pattern in emission reports. For very different source sectors, huge discrepancies between reported amounts of material available for atmospheric release and their actual atmospheric occurrence are evident. We have developed the concept of "potential emissions" to deal with the problem. "Potential emissions" as derived from the availability of particles to be released are the upper limits to possible release fluxes, but they require confirmation from atmospheric measurements before being accepted to the inventory. When no such confirmation was available, we used emissions calculated according to the lower of the available emission factors. This way TSP emissions for Austria were less than half of the emissi-

ons that could have been estimated when considering the potential emissions. These differences occur for fugitive emissions, they become dominating the large size fractions as well as TSP emissions.

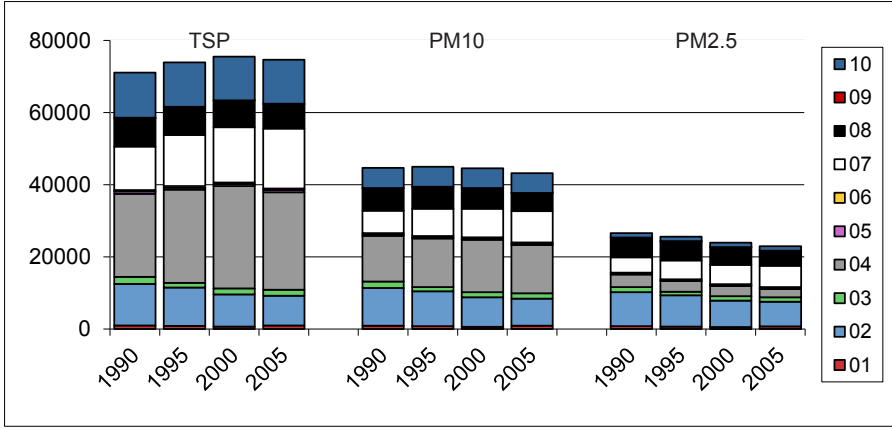


Figure 1: Time series (Winiwarter et al. 2007) for Austrian PM emission estimates (in tons per year). Results are presented by CORINAIR source categories: (01) Combustion in energy and transformation industry; (02) Non-industrial combustion plants; (03) Combustion in manufacturing industry; (04) Production processes; (05) Extraction and distribution of fossil fuels; (06) Solvent and other product use; (07) Road transport; (08) Other mobile sources and machinery; (09) Waste; (10) Agriculture.

The resulting emissions of TSP and the size fractions PM10 and PM2.5 are presented in Figure 1. According to these results, the emissions of TSP in Austria derive from:

- industrial processes (about one third; here potential emissions – and their associated uncertainty – may contribute significantly to the number, as it was not possible to obtain a lower estimate)
- road transport (about a quarter)
- agriculture
- small heating installations

Smaller size fractions (PM10, and especially PM2.5) are dominated by combustion emissions – small heating installations, road transport and other transport make up for most of the PM2.5 emissions.

The trend between 1990 and 2005 indicates increased emissions from road transport, despite of technology improvements, due to the increased transport activity. For small heating installations, even increases in firewood consumptions have been more than matched by the introduction of efficient burners over the last decade, such that overall emissions have decreased.

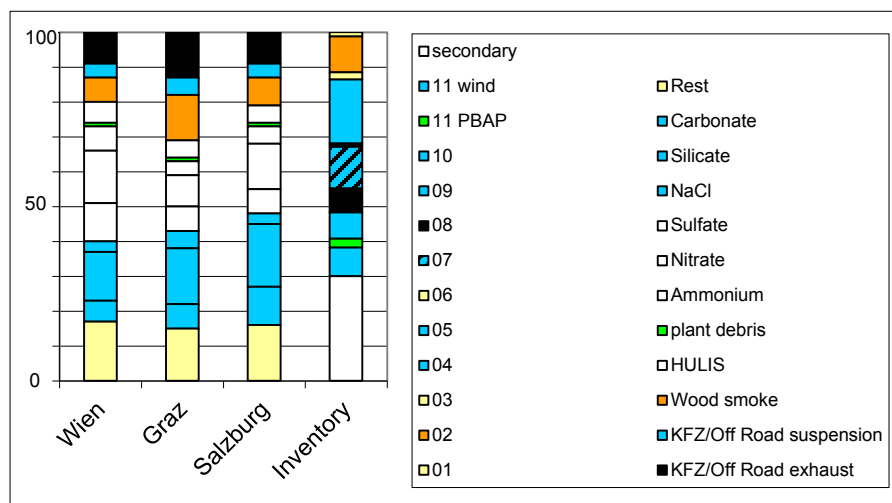


Figure 2: Comparison of AQUELLA source analysis (Bauer et al. 2007) – sources described in right hand column of the legend – to the Austrian inventory, CORINAIR categories in the left column as listed in Figure 1 and include (11) "natural sources" as well as a fraction of 30% secondary aerosol as derived by the source analysis. Colours were assigned to help comparison, black represents soot, orange combustion products, blue stands for mineral compounds, green for organic material and white is secondary aerosol.

Validation of an emission inventory requires an independent set of data. The most independent way to assess emissions is ambient measurements. Figure 2 compares results obtained from ambient measurements using source apportionment (Bauer et al. 2007) to the inventory. While this approach currently is not very detailed, it indicates at least the general applicability of the approach taken.

4. Austrian activities referring to the European situation

Some of the early activities to derive emissions for Europe as a whole have been developed in Austria (Lükewille et al. 2001). This assessment took advantage of the activity information available in the RAINS/GAINS database (see this compendium, pp. 121 ff) and added size-fractionated PM as a new component. Spatial resolution was by countries, results were available in 5 year intervals from 1990 to 2030. The database has recently been expanded to cover also simple chemical speciation: black carbon, organic carbon (Kupiainen and Klimont 2004, 2007), which i.a. have been used to estimate PBAP emissions.

As part of a contribution to COST action 633 "Particulate Matter and Health", a review on PM emission inventories in Europe has been prepared (Winiwarter et al. 2009b). A large body of scientific literature is presented in this review

dealing with multiple aspects of PM emissions in Europe. The overview clearly separates well-investigated areas (especially vehicle emissions, but for transport even the fugitive emissions now have been reasonably well assessed for Europe) and determines the data gaps. Not surprisingly, gaps for Europe refer to the same sources as for Austria: Information on fugitive emissions (caused by wind shear, material transfer processes or other mechanical forces from non-point sources) is sparse. Especially activities in industry (quarries), agriculture, but also natural particle formation like sea salt and wind blown dust will require further attention. PM is an intensely studied area, and improvements may be expected with validation methods in place as shown in Figure 2 for Austria.

5. Conclusions

Improving the Austrian emission inventory would require additional measurements of those sources where potential emissions may play a role. Currently, industrial processes (quarries) are the only source where emissions have been calculated from their potential emissions, i.e. the maximum available estimate. This source may be overestimated, but no other information has been available. Combustion emission estimates would strongly benefit from better activity estimates for domestic heating, especially concerning the quantity of wood burnt in modern installations.

Most promising abatement options regard phase-out of outdated technology. This includes old Diesel engines used in "Other transport", as well as old, inefficient equipment to burn wood. Possibly measures in limestone quarries could help reduce fugitive emissions.

Comparison with alternate emission estimates and results of source apportionment studies show no major discrepancies between these two independent approaches. While further, more detailed and focused comparison exercises are needed to arrive at a comprehensive conclusion, this outcome supports the results and the reliability of the new inventory.

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Fugitive dust emission abatement

Wilhelm Höflinger

1. Introduction

The relative importance of sources of atmospheric dust changed over the last years. While dust emissions from fugitive dust sources have been increasing still, the total dust emission is decreasing (Bernicke and Cohors-Fresenborg 2009). This is due the fact that conducted source (non-fugitive) emissions were reduced as a consequence of highly efficient separation devices which were successfully installed. For fugitive dust sources the installation of suitable abatement methods is still a quite challenging task and therefore significant reductions were not achieved yet. One aspect is that the emission concentration of a fugitive dust source is not easily detectable, which should be the first step for designing an efficient abatement method. Therefore considerable scientific efforts to develop technologies for dust reduction in Austria focussed on fugitive emissions and to the developing of suitable abatement methods.

2. Sources of fugitive dust emissions

Fugitive dust emissions can be emitted from the following sources (see also the detailed assessment in this compendium, pp. 4 ff):

- Resuspension of dust from paved and unpaved roads (car traffic)
- Building site and roadworks: demolishing of buildings
- Wind erosion: farmland, bulky solids material heaps
- Agricultural processes
- Handling of bulky solid material

Theoretical studies were carried out to better explain the emission situation in the area of fugitive dust emissions. Scientific investigations described here concentrated on the sources of bulky solids handling and resuspension from roads. For this purpose, the typical procedures of bulky solids handling were analyzed as actually occurring in Austrian industry. The influence of these processes on dust emissions was evaluated (Trenker and Höflinger 2001b). Furthermore, the resuspension of dust from paved road due to the car traffic were analysed over more than one year for the city of Vienna (Koschutnig et al. 2003, Höflinger and Koschutnig 2003). Rheina-Wolbeck and Höflinger (2003) use all model approaches to assess the dust reduction potential for the main dust sources of the city of Vienna.

3. Dust generating mechanism during falling of bulk solids

Dumping dry solids, using gravitational forces for material transfer, is the most important handling procedure of bulky solids associated with dust release. Therefore the physical mechanism during such dumping processes of bulky solids were investigated in detail and the reasons responsible for dust generation were worked out (Trenker and Höflinger 2002, Ehrenberg and Höflinger 2002, Rheina-Wolbeck and Höflinger 2005, 2006a-d, Rheina-Wolbeck 2006). Rheina-Wolbeck and Höflinger (2006d) also developed recommendations to optimally design dust capture devices for such bulk solids handling procedures. Designing of an encased system, these authors recommend to adjust the suction flow of the capture devices such that the back pressure area in the encased volume is minimized (see Figure 1).

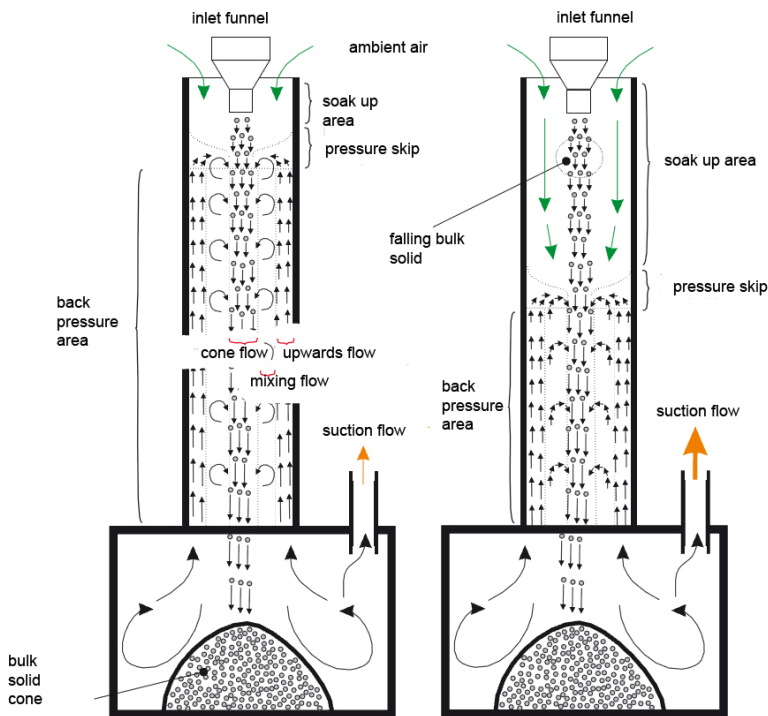


Figure 1: Dust generation of falling bulk solids in encased systems.

Further a testing method was worked out by which the dust generation ability of different bulk solids can be classified and compared. For this purpose a so called falling apparatus was developed, by which the generated dust can be related to the mass of falling bulk solids (Trenker and Höflinger 2001c). By this method it can be also found out which minimum moisture content a bulk solids needs, in order to stop dust generation (Trenker and Höflinger 2001a).

4. Minimisation of the dust generation from bulk solids by water spraying

Generally, there are 3 ways to reduce dust generation in bulk solids handling. The first method is to optimise the operation parameter of the handling process or to change the product properties (compacting of powders to pellets by way of moistening) with the goal of less dust emission. The second method is to enclose the dust generation area and to suck off and filter the generated dust over a bag filter. The third method is to spray water into the dusty air in order to precipitate the dust particles. For this purpose special nozzle types are used which can produce very fine droplets to ensure high specific area for dust capturing with low water consumption. Mathematical models simulate the water consumption in relation to the efficiency of the spraying nozzle on dust minimisation (Höflinger et al. 2008a-b, Zhang et al. 2008, Faschingleitner et al. 2009a-b). Due to the low water consumption and the very fine droplet generation, water evaporation is becoming significant, especially for low air humidity, which was also considered during model development (Grundnig et al. 2006, Höflinger et al. 2009).

Looking at the third method of water spraying used for moving bulk solids (e.g. dedusting of conveyor belts), a more detailed analysis had the goal to identify the relevant separation mechanism, when the area around moving bulk solids will be sprayed with water. The results show that the moistening effect of the bulk solids has by far the dominant effect on dust minimisation compared to the capturing mechanism of the dust particles by the droplets (Faschingleitner et al. 2010a-b, Faschingleitner and Höflinger 2010, 2011b).

Because of these findings the scientific focus was laid to optimize water distribution on the bulk solids, for best dust reduction while keeping water consumption low. Spraying nozzles do not homogenously distribute the water over the area of bulk solids, generating water puddles next to dry areas where unwetted material remains as source of dust emission. A mathematical model calculation was developed, by which the moisture input distribution (defined as moistening velocity $v(x)$ representing the water volume applied per area and time) over the radial distance x at the bulk solids area can be quantified for different kinds of spraying nozzles, different operation parameters, like the water volume flow dV/dt of the nozzle and the nozzle distance from the bulk solids h (Figure 2).

Furthermore a numeric calculation method was worked out by which the spraying device of a conveyer belt transfer station can be optimally designed for minimum dust generation and lowest water consumption. For this calculation the results from a bulk solids falling apparatus are needed, which quantifies the necessary minimum moisture content of the regarded bulk solids for less dust generation (Figure 3).

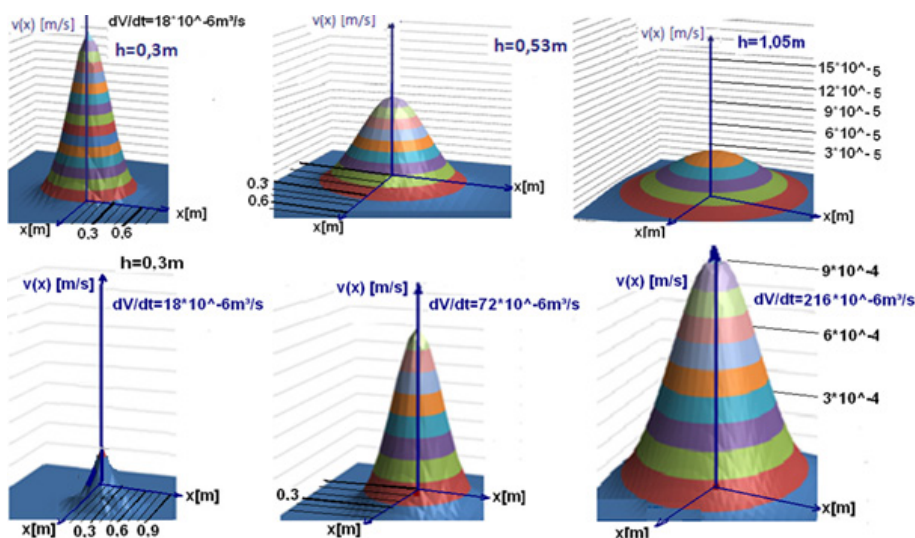


Figure 2: Moistening velocity $v(x)$ as input distribution profile over the radial distance x at the bulk solids area for a spraying nozzle for different nozzle volume flows dV/dt and different distances h to the bulk solids area (Faschingleitner and Höflinger 2010).

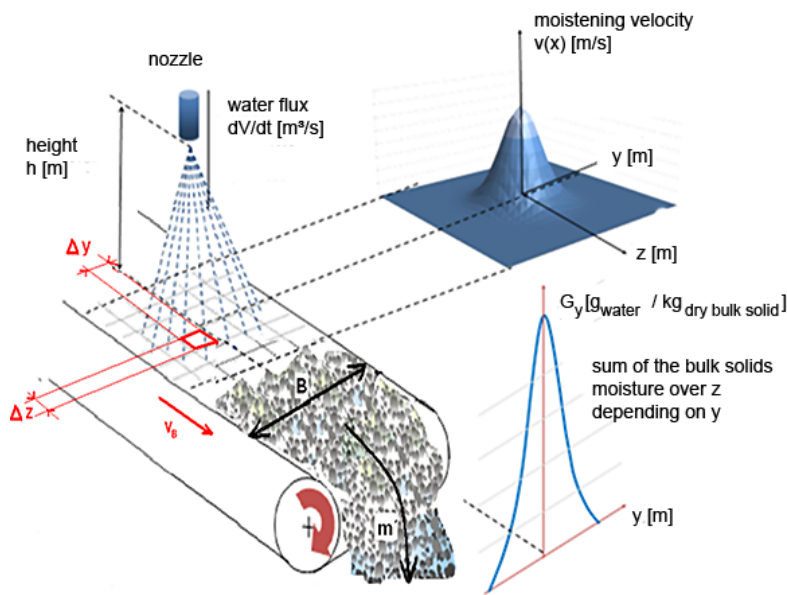


Figure 3: Application of the moisture distribution profile for minimisation fugitive dust emission at a conveyor belt transfer station (Faschingleitner and Höflinger 2011a).

5. Resuspension of dust from roads (car traffic) in the city of Vienna

According to equations developed by the U.S. EPA, resuspension of dust from roads depends on the dust mass, deposited on the road and on the weight of the vehicle travelling over the road. In an experimental study, the so-called silt content, which is the mass of deposited dust mass per road area below $75\ \mu\text{m}$ was detected in Vienna for 44 randomly chosen street points over a period for 17 month (see Figure 4). It can be seen that in autumn the dust deposit on the roads starts to increase due to the falling leaves from the trees and increases then dramatically in winter when road sanding starts. Then silt content steadily decreases until summer. Using the car statistics of Austria and including meteorological data, average PM10 emissions per month over the year can be calculated with the help of the above mentioned EPA equations (Höflinger and Koschutnig 2003, 2004). Results demonstrated that road sanding has a long lasting impact over the year on dust emission and in consequence a list of roads was prepared, describing which roads have the largest dust loads and should be preferably cleaned.

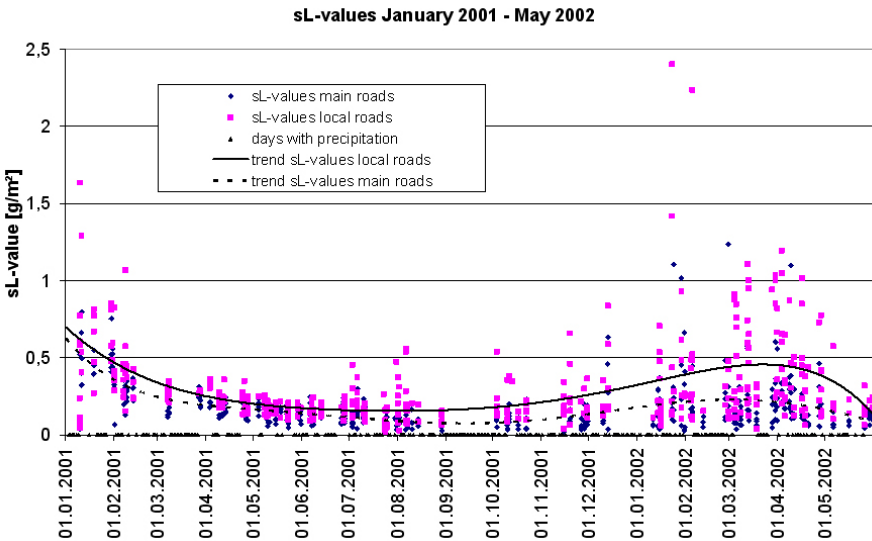


Figure 4: Silt load (sL-) values for 44 roads in the city of Vienna over a period of 17 months (Höflinger and Koschutnig 2003).

Also the effect of road cleaning (washing) was investigated (Koschutnig et al. 2003). Here the silt content was determined before and after passage of the road washing car on different roads, as well as in the days following the

cleaning event up to 2 weeks. It turned out that the cleaning effect depends on the level of the silt content before. At silt contents of about 0.2 g/m^2 the cleaning effect will be eliminated within a period of approximately 2 weeks.

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Physical parameters of atmospheric aerosols

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with contributions by A. Berner, H. Horvath and W. Szymanski

1. Introduction

Atmospheric aerosols originate from a variety of anthropogenic and natural sources and are highly complex physical and chemical systems. Coarse particles (with sizes above a few micrometers) mainly come from the disintegration of bulk material (soil, plant debris, sea spray), while small particles (with sizes of a few nanometers to some tens of nanometers) either are emitted directly from combustion or some industrial processes or formed in the atmosphere by gas-to-particle conversion by chemical reactions of precursor gases. Coarse particles have short residence times in the atmosphere of the order of hours to maybe a few days and are usually only of local importance. Heavy desert dust storms or volcanic eruptions may be of more than regional importance, but they are only sporadic events. Small particles grow fairly quickly into the size range between 0.1 and 2 μm . Particles in this size range have atmospheric residence times of the order of weeks and can therefore be subject to long-range transport and attain more than regional importance. These particles scatter light most efficiently, which leads to visibility degradation in the planetary boundary layer, and because of their scattering properties, they interact with incoming solar radiation and exert a negative forcing on the global radiative balance counteracting the greenhouse effect by infrared-absorbing gases. Light absorbing particles such as black carbon (BC, see this compendium, pp. 32 ff), however, exert a positive forcing and enhance the greenhouse effect. These interactions between (anthropogenic) aerosol particles and the global radiative balance are usually termed the direct aerosol effect (IPCC 2007), while radiative forcing caused by changes in the radiative properties of clouds due to changes in cloud condensation nuclei (CCN, see below) are termed the indirect aerosol effect. Apart from their optical properties, atmospheric aerosols also have effects on human health, which depend on their chemical composition and also on particle size.

Research in the field of atmospheric aerosols has been conducted at the University of Vienna since the early 1970ies, when Othmar Preining established the Aerosol Group, which became an internationally highly respected research group both for basic aerosol science conducted in laboratory experiments and for research on atmospheric aerosols. The group is part of several international research networks and has research cooperations with scientists in Europe, the USA and in Asia (Japan, Thailand, Taiwan). Members of the group chair working groups of international bodies and participate in international

research administration efforts. Over the years, the group also was very active in instrument development. Some of the most important recent method and instrument developments are given in this chapter as well as in this compendium, pp. 32 ff.

2. Cloud condensation nuclei counter CCNC

Cloud condensation nuclei (CCN), which originate from both natural and anthropogenic sources, are a subset of the atmospheric aerosol. They provide the nuclei for cloud droplet formation under the low super-saturations of water vapour typical for cloud formation in the atmosphere (ca. 0.1–2%). An automatic Cloud Condensation Nuclei Counter (CCNC) based on the principle of a static thermal diffusion chamber (originally implemented by Twomey 1977) was developed at the University of Vienna led by Regina Hitzemberger (Giebl et al. 2002, Dusek et al. 2006). It consists of a cylindrical chamber of 1 cm height and 10 cm diameter, which is formed by two parallel plates and a glass ring. The upper plate is kept at a higher temperature than the lower plate, and both are completely wetted with a water film, so humidity is 100% at the temperatures of the plates. After flushing the chamber with the aerosol containing the CCN, the chamber is sealed and linear temperature and water vapour gradients are established, which lead to a supersaturated region at half-height of the chamber where CCN grow to droplets. The droplets are illuminated by a laser beam passing along the centre line of the chamber and a CCD camera takes pictures of the droplets at user-selected time intervals. After a measurement cycle, the chamber is flushed with fresh aerosol, then sealed again and the next measurement cycle begins. Intensive field measurement campaigns were conducted with this instrument on Sonnblick (Hitzemberger et al. 1999) and Rax (Hitzemberger et al. 2000), in the urban aerosol of Vienna (Burkart et al. 2011), and also in the exhaust of aircraft engines under different operating conditions (Hitzemberger et al. 2003).

3. Inertial Impactors

Berner low pressure impactors (BLPI)

Axel Berner started to develop of cascade impactors at the University of Vienna already in the 1970ies (Berner 1978) and is still active in this area of research and instrument development. Cascade impactors segregate the aerosol particles into several size classes according to their mass and deposit them on impaction plates covered with suitable substrates for chemical or gravimetric analysis. In an impactor stage, an aerosol flow with constant volumetric flow rate is split into one or more jets with defined velocity which are deflected by an impaction plate. Particles with masses above a certain limit can not follow

the stream lines of the flow and are deposited on the plate. Smaller particles stay airborne and are carried along with the flow. In a cascade impactor, the velocity of the jets increases from stage to stage (the number of nozzles increases, while their diameter decreases), so particles with successively smaller masses are deposited. In conventional impactors operating at atmospheric pressure, particles smaller than about $0.3\ \mu\text{m}$ diameter cannot be deposited. If the pressure inside the impactor is reduced from stage to stage, however, smaller particles can be collected. Current low pressure "Berner-impactors" separate the aerosol into five to 11 size classes according to specifications. The most widely used low pressure cascade impactors cover the size range between 0.06 and $16\ \mu\text{m}$ with 9 stages and operate with flow rates of 25 or 30 Lpm. Pressure drops at the stages with the lowest cut sizes can reach $0.1\ \text{atm}$. Impactors with higher sampling flow rates (70 Lpm; used e.g. by Hitzenberger et al. 2006) or impactors with rotating stages that create uniform deposits were also constructed (Berner et al. 1996). Measurements of mass size distributions and size distributions of chemical species are performed world wide with Berner impactors (e.g. Berner et al. 2000, Berner et al. 2004). Latest developments include high temperature low pressure cascade impactors for stack sampling (Tursic et al. 2008).

Virtual impactors

Virtual impactors are a relatively new instrument development area led by W. Szymanski at the University of Vienna. In these impactors, particles are not deposited on impaction plates, but impact on "virtual" surfaces formed by openings through which part of the aerosol flow (the minor flow) is diverted from the total flow and collected on a filter. The latest development is the cascade virtual impaction surface impactor CAVIS, which is equipped with an omni-directional sampling head and allows parallel sampling and measurement of ambient particulate matter in size classes with separation boundaries at $10\ \mu\text{m}$, $2.5\ \mu\text{m}$ and $1\ \mu\text{m}$ aerodynamic diameter for PM₁₀, PM_{2.5} and PM₁ measurements. The major flow after the last stage contains PM₁ particles which are collected on the final filter. Multiple nozzles are used in order to maintain a pressure drop as low as possible across the whole device. As only small fractions (10%) of the total flow are drawn through each filter, the filter deposits are exposed only to the small fraction of the overall flow entering the CAVI, which minimizes the possibility of chemical modification of the deposits. As the filters can be easily removed, the separated fractions can be extracted from the CAVI in the airborne state and be measured by an alternative method. The upper limit of the size measuring range is determined by the adjustment of the inlet slot on the omni-directional sampling head and can be varied from 50 to $100\ \mu\text{m}$. Total flow rate through the instrument is 12.5 Lpm. In a recent study,

the CAVI was used to investigate e.g. the optical properties of PM1 aerosol in Vienna (Sabbagh-Kupelwieser et al. 2010).

4. Electrical mobility spectrometers

Vienna-type DMA

"Vienna-type DMAs" (differential mobility analyzers) have been developed at the University of Vienna by Georg Reischl since the 1980ies (Reischl 1991, Winklmayr et al. 1991) and are used all over the world. These instruments classify charged aerosol particles according to their mobility in an electric field. The instruments are based on cylindrical condensers with adjustable voltages. The aerosol is first passed through a charger to establish charge equilibrium for the particles and then introduced into the condenser in a flow parallel to the central electrode. Depending on their size and charging state, the particles migrate to the electrode and are deposited there at distances from the inlet given by their electrical mobility. At the end of the electrode a small fraction of the flow is diverted through a slit. Depending on the (adjustable) voltage, particles with a specific mobility pass through this slit and are counted either with a condensation particle counter or measured with a Faraday-cup electrometer. Scanning mobility particle spectrometers (SMPS) consist of a DMA with automatically adjusted voltage to measure the aerosol number size distribution within ca. 10–20 minutes depending on the size range. SMPS for atmospheric applications typically have an upper cut size of 1 μm and lower cut sizes around 10 nm. Other instruments measure in the size range between 10 and 100 nm (Heim et al. 2004) or in other size ranges (e.g. 5–350 nm for emission monitoring). The most recent development are DMAs for the nano-size range. The UDMA ("ultra-fine-DMA", Steiner et al. 2010) gives high resolution measurements in the ultrafine size range (1–5 nm).

Parallel differential mobility analyzer PDMA

The PDMA is an extension of a DMA which allows for a more complete characterization of airborne particles (Patent AT502207A1, WO2007016711A1: Method for classifying and separating of particles and device for carrying out said method). The PDMA consists of two DMAs. One (DMA1) acts as a scanning mobility spectrometer and records the entire size distribution of an aerosol. The other (DMA2) allows the selection of a very specific size fraction for further analytical purposes. The scanned spectra can be measured by a Faraday Cup (FC) based aerosol electrometer, or by a condensational particle counter (CPC). Moreover, a quantitative characterization and interpretation of size spectra of non-spherical particles, where the shape might influence the measurement, can be done in a straightforward way. Parallel with the scan-

ning DMA 1 which scans and delivers the complete size spectrum of the investigated particles, an identical separation unit DMA 2 is in operation and can be set to one given voltage value (separation) and used for sampling or enrichment (collection) of the one selected size class of particles, hence the acronym PDMA. The extracted particles from DMA2 can also be injected into further characterization instruments without disrupting of the operation of the scanning DMA1. The instrument was already used e.g. to analyze nanoparticles (Allmaier et al. 2008).

5. Optical methods

Dual wavelength optical particle spectrometer DWOPS

Light scattered from a particle into a given angular range is determined by three parameters – the particle size, and the real and the imaginary part of the complex refractive index. Common optical configurations of optical particle counters (OPC) consist of a single light source and a detection system measuring the light flux scattered by the particle into a defined angular range. With these OPCs, no additional information about the particle can be obtained besides its size, but even this information is limited by the need to calibrate an OPC for specific refractive indices. The Dual Wavelength Optical Particle Spectrometer (DWOPS, development led by Wladyslaw Szymanski) is a pre-prototype which measures and evaluates light from two different lasers scattered by an individual particle into four different angular ranges (10° – 30° and 150° – 170°) in the forward and backward directions with respect to the direction of propagation of each laser. This scattered light is then separated by the dichroic beam splitters according to the wavelength, measured by an appropriate detector and converted into a voltage pulse with a magnitude proportional to the amount of scattered light. This procedure yields a quadruple set of independent voltage pulses for each single particle, in contrast to conventional OPCs which measure a single pulse from every detected particle. This set of four data is then compared in real-time with a pre-computed matrix which consists of four columns. Each row in this matrix was calculated for a particle of a certain size, and a real and an imaginary part of the refractive index. A fit procedure finds a quadruple of theoretical values from the matrix which best matches the quadruple of measured values.

For spherical particles the DWOPS (Nagy et al. 2007) allows accurate particle sizing (currently from about 300–3000 nm) together with an assessment of a real (n) and an imaginary (k) part of a complex refractive index (m) with an accuracy of about 15% in the range $n = (1.2, 2.0)$ and $k = (0.0, 1.0)$. For spherical particles the DWOPS technique does not require any re-calibration when the refractive index of measured particles changes, because size and complex refractive index are measured for each detected particle.

Telephotometer

It is a well known fact that an increased load of atmospheric aerosol particles gives rise to a decrease in visibility: The particles in between the observer and a visible object attenuate the light from the object and scatter daylight, thus altering the appearance of the object and making it more similar to the background and thus less visible. The maximum distance of an object recognized is inversely proportional to the extinction coefficient of the aerosol.

The telephotometer developed at the University of Vienna by Helmuth Horvath measures in analogy of a human visibility observation. It consists of a telescope with a spectrometer attached to it and determines the radiance of a small spot of the object, the background and a reference object (Horvath 1981). From this the spectral extinction coefficient of the atmospheric aerosol can be derived. After subtraction of the Rayleigh scattering of the gas molecules the spectral extinction of the aerosol is obtained. Using an inversion procedure the size distribution of the aerosol can be inferred. An example is the growth of the particles due to increase of humidity (Horvath 1996). Combining the horizontal extinction measurement with the determination of the vertical optical depth permits the determination of the scale height of the aerosol (mixing height, Horvath et al. 2002). The majority of the optically active particles in the atmosphere is below 1 μm , thus the extinction coefficient is a good characterization of the particles in the PM1 fraction (Sabbagh et al. 2010a, b).

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Black and brown carbon

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1. Introduction

Carbonaceous material plays an important role in atmospheric aerosols. Its origin can be anthropogenic (emissions of primary particles and precursor gases for secondary organic aerosol mainly by combustion processes and emissions of volatile organic carbon by various processes) or biogenic (emission of primary particles and precursor gases by plants or through the degradation of biological material). In this section, the focus is on black carbon (BC) or elemental carbon (EC) and "brown carbon" (BrC), which originates mainly from biomass combustion, although other sources are also possible (e.g. Gelencser et al. 2002). BC is formed by incomplete combustion of carbonaceous (mostly fossil) fuels and emitted directly as primary particles. BC and BrC absorb visible light and therefore play a role in anthropogenic climate change (IPCC 2007) and both have been identified as important contributors to health effects of anthropogenic aerosols (BC: Pope and Dockery 2006; wood smoke: Bolling et al. 2009). As wood smoke contains BrC, a section on wood smoke studies in Austria is also included here.

The nomenclature is rather operational. Organic carbonaceous material is usually called organic carbon (OC). This material does not absorb visible light and is thermally unstable. Depending on the substances, some OC can be highly volatile already at ambient temperatures. BC or EC are strongly light absorbing and are not considered to be organic material. Typically BC or EC consist of >95% carbon and may have some graphitic structure. If analysis of this fraction is performed with optical methods, the term black carbon (BC) is used, because of its strong absorption of all wavelengths in the visible spectrum. If analyses are performed with thermal methods, the term elemental carbon (EC) is used, although "thermally refractory carbon" might be more appropriate. In both thermal and optical techniques, separation of EC and BC from OC is quite difficult. One of the major confounders for both optical and thermal techniques is brown carbon (BrC), a mixture of high-molecular weight organic compounds which absorb visible light to some extent with higher absorption at short wavelengths, and which is thermally quite refractory (Andreae and Gelencser 2006). Wood smoke contains BrC, but also e.g. Na and K, which also interfere with thermal measurements of OC and EC and can have quite some influence of the OC/EC split.

2. Methods to measure BC (or EC) and BrC

The methods can be grouped roughly in two categories: optical and thermal, although the thermal methods also use optical techniques to improve the separation between OC and EC.

In Austria, two teams of scientists located at the Vienna University of Technology (Heidi Bauer) and at the University of Vienna (Regina Hitzemberger) are active in developing methods and in method inter-comparison efforts. At this time, all methods are used by one or both Viennese teams unless indicated otherwise. The team at the University of Vienna specializes more on optical and thermo-optical techniques, while the team at the Vienna University of Technology specializes more on thermal and chemical techniques, although there is quite some overlap between the groups.

Optical methods

Most optical methods measure the transmission (or reflection) of light through (or by) a sample containing BC. The resulting signal for light attenuation has to be converted to a mass concentration of BC, which is usually performed by using specific attenuation coefficients of BC obtained from a combination of the optical method and a thermal one. Optical techniques often suffer from losses of light scattered by the particles, which is erroneously attributed to light absorption resulting in an overestimation of the BC concentration. The integrating sphere technique, which will be described separately, needs to be calibrated with proxy substances for BC, but this calibration is not linked to a thermal method to determine EC.

Currently three optical on-line methods are widely used: the multi-angle absorption photometer (MAAP) developed by Petzold and Schönlinner (2004, single wavelength), the particle soot absorption photometer PSAP (Bond et al. 1999, three wavelengths) and the aethalometer developed by Hansen et al. (1984, currently single-wavelength, seven-wavelength and single-wavelength micro-aethalometer instruments are available). The calibration constant for the aethalometer is only obtained from thermal measurements on Diesel soot, while the other optical methods apply additional correction procedures based on radiative transfer calculations (the MAAP) or other correction schemes (e.g. the aethalometer correction by Weingartner et al. 2003, or the PSAP correction by Virkkula et al. 2005).

Off-line methods include the light transmission method (LTM, based on the original paper by Hansen et al. 1984), the integrating plate method (originally developed by Lin et al. 1973, and later extended also by Horvath 1997), and the integrating sphere technique, which has recently been extended to measure

also BrC and is currently the only method that gives quantitative estimates of BrC from atmospheric samples.

Except for a multi-wavelength aethalometer and a PSAP, all optical methods except the LTM are available at the University of Vienna. The LTM is available at the Vienna University of Technology.

Thermal methods

Thermal methods rely on the different temperature sensitivity of organic and elemental carbon. Volatile and semi-volatile material evolves from the samples when they are heated up from room temperature to temperatures of some hundred °C (specified by the temperature protocols of the different instruments or analysis procedures), while elemental carbon stays stable up to ca. 450°C even in oxidizing conditions. In these methods, the samples are heated in a carrier gas stream and the evolving carbonaceous material is converted either to CO₂ or CH₄, which is analyzed quantitatively. The carrier gas for the evolved material can be inert (usually Helium) or contain oxygen (from small amounts of O₂ added to the inert carrier gas to pure O₂). One of the earliest methods was the thermogram method developed at the Vienna University of Technology (Malissa et al. 1981) which, however, had to be modified because of the thermal behaviour of OC.

Organic material, which normally does not absorb visible light, can blacken ("char") when exposed to elevated temperatures. This pyrolytically formed "elemental" carbon (PEC) is thermally quite stable and would lead to an underestimation of OC and a concurrent overestimation of EC if no correction were applied in the thermal methods. In the now rather historic Cachier method (Cachier et al. 1989), different hold times were chosen for the two-step temperature protocol to minimize charring. Most currently used thermal methods record the signal of a laser beam transmitted through or reflected from a sample and set the split point for the OC/EC separation when the laser signal has reached again its initial (i.e. pre-charring) intensity. Among those thermal-optical techniques are the current thermogram of the Vienna University of Technology (described in detail by Jankowski et al. 2008), the Sunset Analyzer (Birch and Cary 1996, used in the NIOSH-Protocol) and the thermo-optical method developed by Chow et al. (1993, used in the IMPROVE-Protocol). In the recent EUSAAR project, the various temperature protocols and charring correction schemes were analyzed for background aerosols and a new protocol was developed (EUSAAR protocol, Cavalli et al. 2010). As atmospheric samples can also contain carbonates, which typically originate from soils or building materials, carbonate corrections should also be performed, e.g. the correction scheme developed recently at the Vienna University of Technology by Jankowski et al. (2008).

In general, thermal methods depend crucially on the separation procedure to differentiate OC and EC. If only Diesel soot is present in a sample, the separation is rather straight-forward, but wood smoke contributions to the aerosol pose substantial problems. Wood smoke contains thermally refractory organic material, which should be attributed to OC, and trace elements such as Na or K which lower the combustion temperature of EC. In the first case, EC will be overestimated, while in the second it will be underestimated. At this time, the "correct" way to deal with samples influenced by wood smoke in the thermal analyzers is still under debate. In a current study, these interferences are quantified by the University of Vienna team (Hitzenberger and Rosati 2010).

Sunset analyzers capable of performing all temperature protocols as well as charring corrections by transmission and reflection are available at both the University of Vienna and the Vienna University of Technology, where measurements can also be performed with the thermogram and Cachier methods. A semi-continuous Sunset Analyzer (Bae et al. 2004) is available at the Umweltbundesamt.

Other methods

Aerosol light absorption and consequently BC can be measured in situ with a Photoacoustic Absorption Spectrometer (PAS, Arnott et al. 1999) or a cavity-ring down instrument (Moosmüller et al. 2005), although these techniques are quite expensive and are not used at the moment in Austria.

Measurement of black and brown carbon – integrating sphere method

The integrating sphere technique (developed originally by Heintzenberg et al. 1982) was extended by Hitzenberger et al. (1996) to measure BC in atmospheric samples. In this technique, a sample is introduced into an integrating sphere, i.e. a sphere coated inside by a perfectly diffusing surface. The interior of the sphere is illuminated with monochromatic light, and the light flux is measured with a silicon photo diode. In the presence of a light absorbing sample, the light flux is decreased, and this decrease can be linked to e.g. EC using a calibration curve obtained with a suitable EC proxy. As light scattered by the sample is also collected by the detector, the IS method does not suffer from losses of scattered light as do the usual filter-based light transmission methods (e.g. the aethalometer or the PSAP). A detailed description of the operating principle and the advantages of the technique compared to other optical techniques is given by Hitzenberger and Tohno (2001). The need to calibrate the sphere with proxy substances, which is quite a complex procedure, actually led to the development of a quantitative estimation of the amount of BrC concur-

rently with the determination of BC (Wonaschütz et al. 2009). The different wavelength dependence of light absorption by BC and BrC, which is visible in the wavelength dependent calibration curves obtained with proxies for Diesel soot and BrC, is used for the quantitative differentiation between these two parameters. This new extension of the integrating sphere method is up to now the only way to arrive at concentrations of BrC in the atmospheric aerosol.

Determination of biomass smoke

As biomass smoke is probably the largest single source for BrC (Andreae and Gelencser 2006), some discussion should be included in this chapter. Methods to analyze atmospheric samples for biomass smoke as well as for source attribution of OC to biomass smoke are an active research area of the Vienna University of Technology team.

Biomass smoke is a complex mixture of organic and inorganic substances, which depends also on the fuel type and the firing conditions. Particulate emissions from manually fired combustion systems are composed mainly of organic compounds and EC while emissions from automatically fired systems are around an order of magnitude lower and contain mostly inorganic components (Schmidl et al. 2011). As most of the identifiable substances in biomass smoke also have other sources, tracers and tracer profiles are used to determine the amount of wood smoke in atmospheric samples. Traditionally, potassium (K) was used as a tracer for wood smoke (Fine et al. 2001), but recently, anhydrosugars formed during the combustion process have come into use. Levoglucosan, mannosan and galactosan are analyzed by high performance liquid chromatography (HPLC) and used to determine the concentration of biomass smoke. Levoglucosan is a major by-product from cellulose pyrolysis and a marker for wood combustion in ambient samples (Simoneit et al. 1999). In a recent study on smoke samples from common Central European wood types, Schmidl et al. (2008a) found that levoglucosan contributed 4–15% by weight to the smoke. Mannosan, which is formed during pyrolysis of hemicelluloses, was found useful to distinguish between softwood and hardwood combustion, as smoke from conifers contains at least four times higher concentration than smoke from deciduous trees, but with 0.4% the content is much lower than that of levoglucosan. Galactosan concentrations in woodsmoke are 10–50 times lower than levoglucosan concentrations, but about equal in smoke from open burning of leaves (Schmidl et al. 2008b). The ratio of levoglucosan/galactosan may therefore help to identify pollution episodes influenced by leaf burning emissions such as from open garden fires.

3. Measurements of BC and BrC in Austria

Method inter-comparison studies – general

Despite more than three decades of intensive efforts, no standard technique for BC (or EC) measurements exists. Over time, dozens of method inter-comparison studies were performed, but usually only two or a few methods were compared. Watson et al. (2005) give a fairly comprehensive overview over inter-comparison studies conducted up to about 2004.

As the Austrian scientists working in the field of carbonaceous particles in the atmosphere are part of several international networks, important international method inter-comparison studies were coordinated by the teams of the Vienna University of Technology (Schmid et al. 2001) and the University of Vienna (Hitzenberger et al. 2006, Reisinger et al. 2008) or performed in cooperation with these teams (Currie et al. 2002, ten Brink et al. 2004). Regina Hitzenberger is currently a member of the CEN/TC 264 Working Group 35 "EC/OC in PM", which endeavours to set a standard measurement method for EC and OC on PM_{2.5} samples. The Vienna University of Technology group participated in the EU projects CARBOSOL and POLYSOA, and the University of Vienna group in the EUROTRAC-II Field project InterComp2000 (coordinated by K. Müller, IfT Leipzig).

Very comprehensive studies involving a large set of techniques and laboratories were performed by Schmid et al. (2001) on a limited set of filter samples obtained from an urban kerbside site and by Currie et al. (2002) on a PM reference material. A recent large-scale method inter-comparison study was part of the EUROTRAC-II project InterComp2000, where atmospheric aerosols were sampled in an intensive field campaign at the rural site Melpitz, Germany (ten Brink et al. 2004) in spring 2000. In general, the large-scale studies show that total carbon (the sum of OC and EC) can be determined within less than 10% with the different thermal methods employed at different laboratories.

For EC, however, results obtained by different methods can vary by an order of magnitude (Schmid et al. 2001) for kerbside samples if thermal methods without charring correction are included in the data set. If only thermal methods with charring correction are considered, the variation is much lower (ca. 25%) and the EC concentrations are lower by ca. 20% than the average over all methods used in the study. For background (or rural aerosol) in springtime in Melpitz, the picture is similar. Method differences for EC and/or BC were found to be within a factor of three (ten Brink et al. 2004), although the time series of BC or EC were highly correlated.

Method inter-comparison studies in the Vienna aerosol – influence of BrC

In summer 2004, an intensive international inter-comparison study was performed in the roof laboratory of the University of Vienna team (Hitztenberger et al. 2006). Practically all methods in use at that time in Europe were run in parallel to obtain BC and EC concentrations. The results were highly surprising, as no significant difference could be found between the methods. Although there was of course quite some variation on a day-by-day basis (Figure 1), the campaign averages obtained from the different methods were within their respective standard deviations.

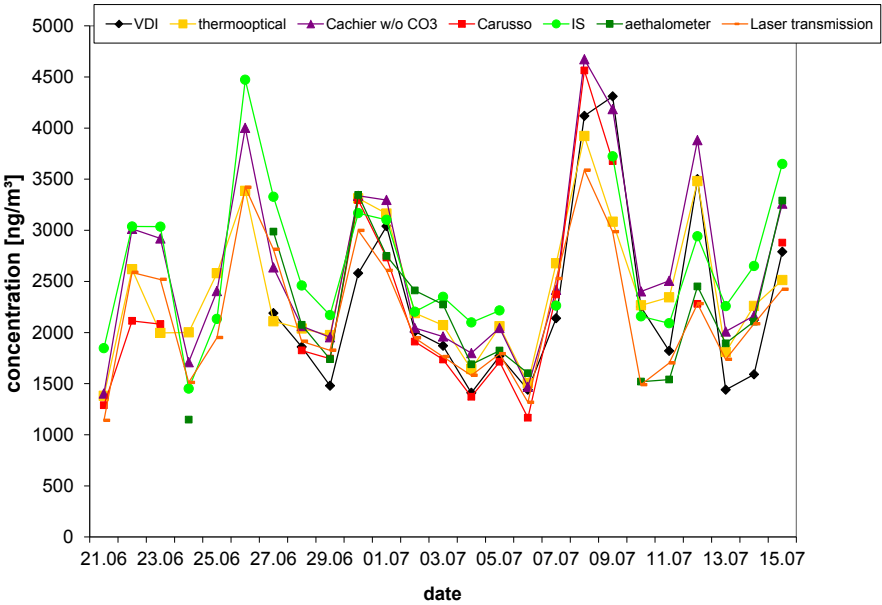


Figure 1: Daily variation of BC and EC during the summer method inter-comparison study in Vienna, all data. (from: Hitztenberger et al. 2006). "Carusso" is the old acronym for the MAAP instrument.

In winter 2006, the study was repeated (Reisinger et al. 2008). On mild days, method differences were similar to summer, but on cold days, method differences of up to factors of 4 were found. The highest values were obtained by the Cachier method and the MAAP, and the lowest by the two different thermal protocols (TOT (A3) and TOT (NIOSH) of the Sunset analyzer (Figure 2a). At that time, the method to separate BC and BrC (Wonaschütz et al. 2009) was already available. We found that method differences were most severe when the BrC content of the aerosol was high. The BC concentrations obtained from the integrating sphere after the separation of BrC and BC were in the range of the

lower concentrations, but still appreciably above the concentrations measured with the Sunset instrument (both protocols, Figure 2b).

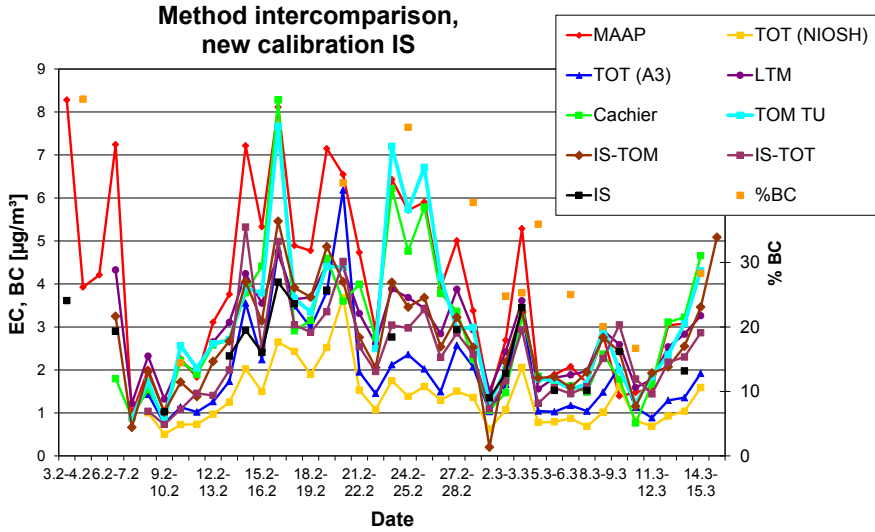


Figure 2a: daily variation of BC and EC during the winter method inter-comparison campaign in Vienna; all data. (from: Reisinger et al. 2008).

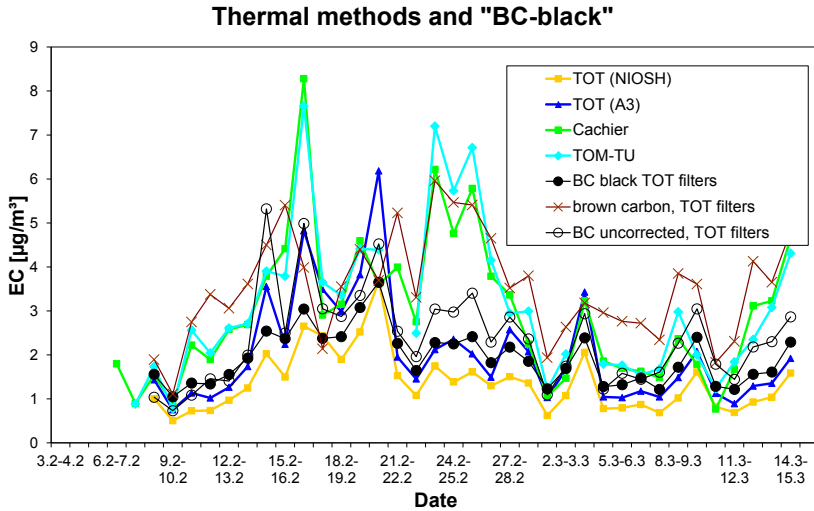


Figure 2b: daily variation of EC and BC (only integrating sphere, corrected and uncorrected for BrC) and BrC during the winter method inter-comparison campaign in Vienna (from: Reisinger et al. 2008).

Brown carbon during a biomass burning episode (Easter fires) in Styria

In rural Austria, garden waste was usually burnt in open fires until air quality regulations prohibited these fires several years ago. Nowadays, fires may be lit only for special occasions, such as the traditional log fires on mid-summer eve and during the Easter night. According to regulations, only dry wood may be burnt, but quite often garden waste collected in the preceding fall is quietly disposed of in the fires. Air pollution can be severe especially in valleys under stable meteorological conditions. One such episode was traced during the measurements for AQUELLA in 2004 (Bauer et al. 2007) in Styria, where PM10 concentrations reached $>100 \mu\text{g}/\text{m}^3$, which was more than twice the 24hr standard value. The results of the EC/BC/BrC measurements were reported by Wonschütz et al. (2009). Figure 3 shows the BC and BrC concentrations obtained with the integrating sphere and EC obtained with the Cachier method and the thermogram TOM-TU method from PM10 filter samples collected in Graz at a kerbside site (Don Bosco), a suburban site (Graz Süd) and a background site (Bockberg) during the Easter weekend 2004. An additional filter sample from Peggau (Easter Sunday 2006) is also included. On Good Friday 2004 (April 9), BrC was present only at one site (Graz Süd) in a very low concentration.

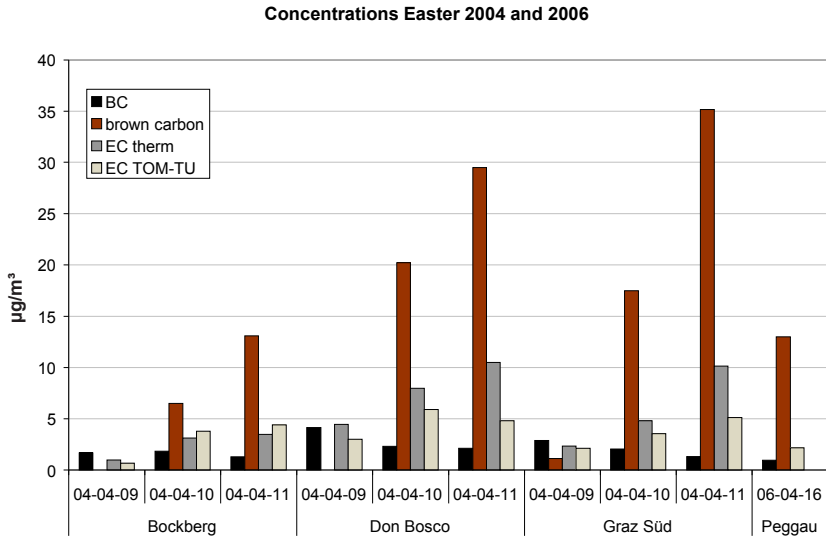


Figure 3: concentrations of BC (traffic derived), BrC (biomass source) and EC determined with the Cachier (EC therm) and thermogram (EC TOM-TU) methods during the Easter weekend 2004 and during Easter Sunday, 2006 (from: Wonaschütz et al. 2009).

Fires were lit during the afternoon of Holy Saturday (April 10) and continued burning during the night. BrC concentrations increased drastically at all sites, and method differences became appreciable with largest concentrations measured by the Cachier method within Graz and the thermogram method at the background station. BC, which was corrected for the influence of BrC, follows the expected traffic patterns with highest concentrations on Friday and lowest on Sunday. The other methods overestimated BC quite severely when BrC concentrations were non-negligible during Easter night and Easter Sunday. Similar method differences were found also for the other Easter sample (Peggau 2006).

4. Wood smoke

Wood smoke is studied by the Vienna University of Technology group both in terms of emissions and emission factors and in terms of wood smoke contribution to ambient aerosols.

In a recent study (Caseiro et al. 2009) the impact of wood burning in Austria was investigated for traffic impacted, residential and background sites in Vienna, Graz and Salzburg. At all sites, wood combustion contributed significantly to PM₁₀ especially during the cold season, when wood is used as a fuel for domestic heating. Concentrations (and contributions to PM₁₀) were higher in background and residential areas, while traffic impacted sites experienced an additional PM₁₀ load from traffic emissions. The contribution of wood smoke to organic carbon and PM₁₀ levels was calculated using a constant ratio of levoglucosan and OC and PM₁₀ respectively which was derived for fire woods typical for Alpine European regions. For OC, levoglucosan concentrations are multiplied by 6.1 and for PM the factor is 10.7 (Schmidl et al. 2008a). The estimated contribution of wood smoke-OC to total OC in PM₁₀ ranged from one third to more than half in the cold season with higher contributions of up to 70% in winter (December, January and February) in the smaller cities and the rural background. Wood smoke can therefore be considered the predominant source of organic material at rural and small urban sites in central Europe. Consistently, wood smoke was an important contributor to PM₁₀ during the cold season, with contributions of around 10% in the larger Vienna region and around 20% at rural sites in the densely forested regions of Salzburg and Styria during the winter months. In those regions the highest relative wood smoke contents was found in residential regions during fall (September till November), when wood stoves are used as auxiliary heating systems in the transition from the warm to cold season. In alpine valleys wood smoke can account even for more than 50% of PM₁₀ (Bauer et al. 2010). Using the relationships between the different anhydrous sugars described in the method section, the combustion of softwood was found to be dominant for wood smoke at all sites.

Data on wood smoke emissions by different fuels as well as by different combustion systems and combustion conditions are important for emission inventories and source apportionment studies. Such studies were carried out by the Vienna University of Technology team (Luisser et al. 2008, Schmidl et al. 2008c, Gonçalves et al. 2010). Emission factors for particulate emissions from different wood types and combustion conditions were determined and the biomass smoke was chemically characterized. More than 50 chemical constituents were analyzed including carbonaceous species, soluble ions, anhydrous sugars, HULIS, n-alkanes, carboxylic acids, PAHs and trace metals.

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Bioaerosols

Heidi Bauer

1. Introduction

Bioaerosols are defined as living airborne particles or parts of them smaller than 100 μm , independent of their viability status. They form an important fraction of atmospheric particulate matter in rural as well as in urban areas. Bacteria and fungal spores dominate in central European PM₁₀ while airborne algae, pollen and moss spores are only very minor fractions in this size range. The importance of bioaerosols is not limited to health risks, viruses, bacteria and fungal spores can spread human, animal and plant diseases, fungal spores and pollen for example can and cause allergic reactions in sensitive people. Bioaerosols can also have effects on climate, acting as cloud condensation nuclei and or ice nuclei they can take part in cloud formation (e.g. Bauer et al. 2003, Deguillaume et al. 2008).

In Austria research on bioaerosols is carried out mainly at the University of Innsbruck, the Medical University of Graz and the Vienna University of Technology. In Vienna research focuses on aerosol carbon balance, analytical methods for the determination of bioaerosols and their nucleation properties. In Innsbruck the field of research is microbial communities in the cryosphere, while health related aspects in indoor and outdoor environments and at workplaces are investigated in Graz.

2. Analytical methods to determine airborne bacteria and fungal spores

Culture methods

For a long time airborne bacteria and fungi have been determined by culture methods after collection on filters, in sampling liquids or directly on different culture media. These methods allow the determination of viable and culturable microorganisms and their identification. Culture methods are widely used for hygienic investigations in exposure studies to airborne microorganisms in workplaces, hospitals, mouldy indoor environments and emission sources such as composting facilities, slaughter houses and wastewater treatment plants (Bauer et al. 2002, Haas et al. 1999, 2002, 2007, 2010a, 2010b, Kock et al. 1998, Posch et al. 2006, Reinthaler et al. 1999, Wuest et al. 1999).

The culturable part of airborne bacteria and fungi (concentrations expressed as colony-forming units CFU m^{-3}), however, represents only a limited part of

microorganisms suspended in the atmosphere. In case of bacteria the culturable fraction is less than 1% of the total count, in case of fungal spores the cultural part accounts for 40% or less of the airborne fungal spectrum (Lappalainen et al. 1996, Lee et al. 2006).

Microscopic enumeration

All bioaerosols – pathogenic or not, allergic or not, dead or alive – are contributors to PM₁₀ and to the aerosol organic carbon (OC), and were assessed in terms of their mass contribution to the PM aerosol in recent studies. Quantitative assessment of bioaerosols can be achieved by different approaches, one of them is counting the individual microorganisms under the microscope after staining with fluorescent dyes (Sattler et al. 2001, Bauer et al. 2002a, Bauer et al. 2008). To assess the biomass-carbon the number concentration of bacteria and fungal spores is multiplied with an average carbon content of 17 fg (Sattler et al. 2001) and 13 pg (Bauer et al. 2002b), respectively. The contribution of fungal spores to PM₁₀ can be derived by multiplying the number count with 33 pg to account for the spore mass (Bauer et al. 2002). The application of microscopic enumeration requires collection of aerosols with liquid impingement and does not allow distinguishing between viable and dead organisms, nor the identification of species.

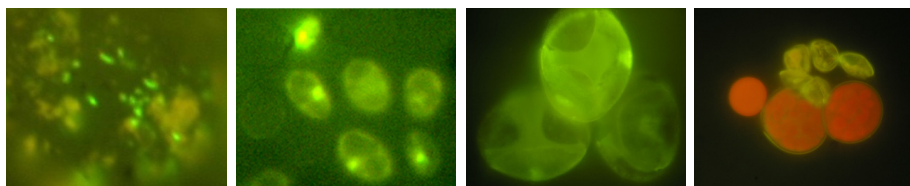


Figure 1: Bacteria, fungal spores, moss spores and pollen dyed with SYBR Gold[®] in the epifluorescence microscope (Bauer, 2008).

Analysis of chemical tracers

A second approach of quantifying total counts of bioaerosols is the determination of the concentration of chemical tracers. A specific tracer for fungal spores is the sugar alcohol arabitol which is a storage substance in fungi and has not been reported to be present in plants or other organisms in central Europe. The arabitol content varies in different species, but an average content per fungal spore, representative for the atmospheric fungal mixture was determined to be 1.2 pg spore⁻¹ (Bauer et al. 2008a). The arabitol tracer technique allows quantifying the concentration of fungal spores together with other organic and inorganic aerosol constituents using loaded filters.

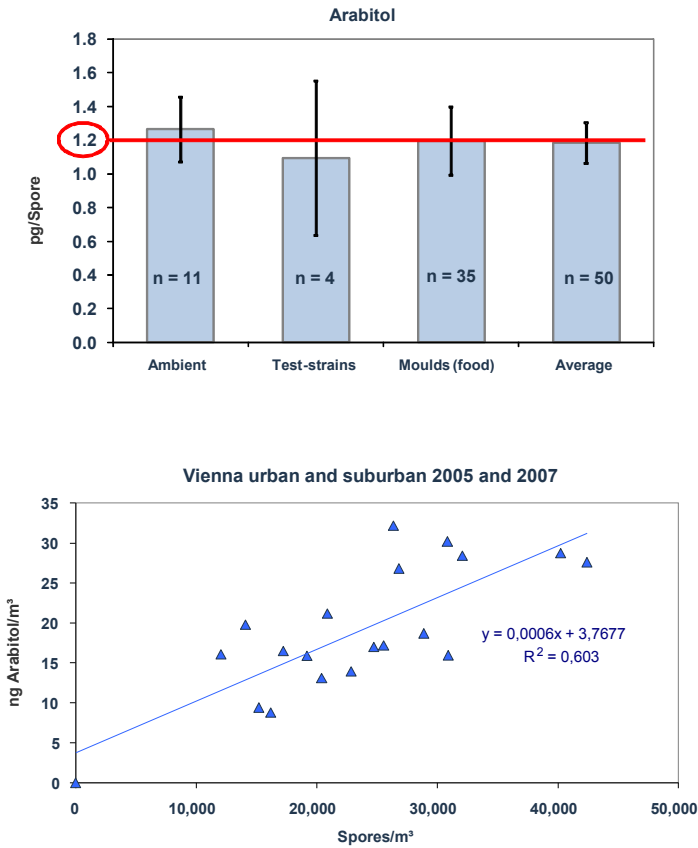


Figure 2: Arabitol – a suitable tracer for airborne fungal spores. Average arabitol content of fungal spores in source (upper graph) and ambient samples (lower graph) (from Bauer 2008).

In-situ analysis

A laser induced fluorescence excitation (L.I.F.E.) technique has been developed being capable to identify the presence of microbiological material in-situ in snow and ice environments (Sattler and Storrie-Lombardi 2010). The technique has been tested in the Antarctica and will be part of the ESA Mars mission scheduled for 2015.

3. Ambient occurrence of bioaerosols in Austria

Occurrence and seasonality of bioaerosols in Austria and their contribution to PM₁₀ and OC₁₀

Concentrations of airborne bacteria and fungal spores (total counts) were determined in extensive field studies in three Austrian cities, at suburban and rural sites and at a mountain site which was representative for the lower tropospheric background (Mt. Rax 1664 m.a.s.l.). Concentrations of airborne bacteria (total counts) determined at Mt. Rax (Bauer et al. 2002a) and in Vienna, were around 25% higher than those of fungal spores. The concentrations of airborne fungal spores showed high seasonal variations with around 35,000–40,000 spores m⁻³ in July at rural and urban sites, respectively. As a monthly average fungal spores OC contributed 15 and 10% to OC and fungal spores mass 7 and 8% to PM₁₀ at urban and rural areas. At most sites a second peak could be observed in October. In winter the concentrations of airborne fungal spores amounted to around 4000 spores m⁻³ at rural and urban sites contributing around 1% to OC and 0.3% to PM₁₀ (Figure 3).

Total emissions of fungal spores in Europe are estimated with 18 kg km⁻² yr⁻¹, this means emissions of fungal spores in the magnitude of around 1400 tons yr⁻¹ in Austria (Winiwarter et al. 2009). A first determination of airborne fungal species at an urban and a suburban site in Vienna indicates that around 20% of the detected spores belong to fungal species known to elicit hypersensitivity (Schüller 2008).

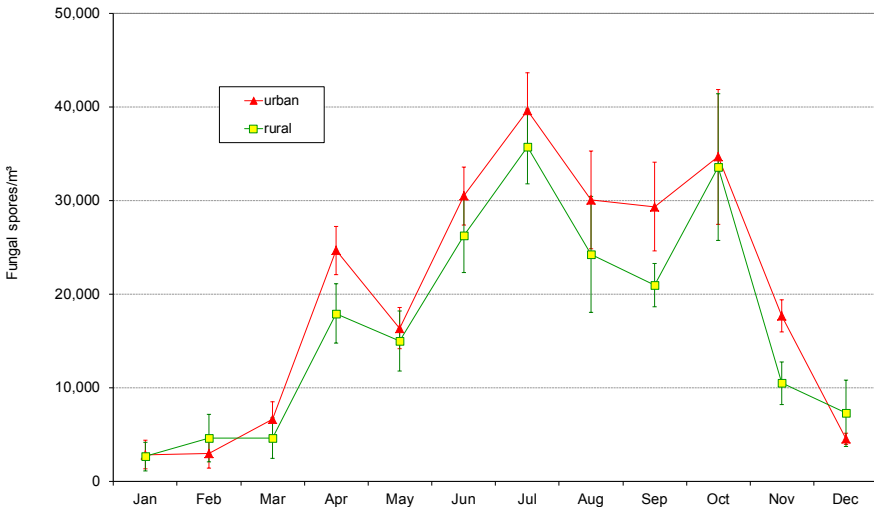


Figure 3: Seasonal variation of the concentration of fungal spores in PM₁₀ in three Austrian cities in 2004 (Bauer et al. paper in preparation).

Exposure studies

Exposure studies were carried out to estimate the potential health risk. Measurements of culturable airborne bacteria and fungal spores were performed especially in waste treatment facilities such as waste water treatment plants (Bauer et al. 2002c, Haas et al. 2002, 2010a), composting facilities (Haas et al. 1999, Reinthaler et al. 1999). Culturable airborne microorganisms were assessed as well in metropolitan areas (Kock et al. 1998), in households (Haas et al. 2007, Gonçalves et al. 2010), wine cellars (Haas et al. 2010b), agriculture (Wust et al. 1999) and in food production (Posch et al. 2006).

Microbial cloud formation

For the Earth's weather and climate system, clouds are of major importance. On the one hand they cool by reflecting parts of the solar radiation and on the other they heat by absorbing solar radiation and by trapping the outgoing infrared radiation. In the discussions about climate change, however, clouds appear as one of the largest non-anthropogenic uncertainties of the earth's radiation balance (IPCC 2007). Not only inorganic atmospheric particles but also some bioaerosols are involved in cloud formation. Bacteria, dead or alive were found to be good cloud condensation nuclei (Bauer et al. 2003). Specific bacterial species and possibly larger bioaerosols are able to act as ice nuclei, lowering the freezing temperature of atmospheric water vapor. Investigations of potential ice nucleating pollen and fungal spores and the responsible microstructures are currently carried out at Vienna University of Technology.

4. Bioaerosols in the cryosphere

Research groups at the Institute of Zoology and Limnology, University of Innsbruck have a long tradition in investigations of microbial communities in the cryosphere. Starting with studies of microbiological life forms in ice and snow of high mountain lakes (Felipe et al. 1995) the group investigated the interactions of the eolian input of microbes and nutrients into the snow and ice forms of High Alpine lakes and glaciers (Psenner 1999, Battarbee et al. 2005) as well as of the effluents (Battin et al. 2001). Tieber et al. (2009) studied the input of radionuclides into cold ecosystems. Thiess et al. (2007) reported about an "Unexpected Response of High Alpine Lake Waters to Climate Warming".

The University of Innsbruck was also involved in a survey of the distribution of several trace elements in contemporary and pre-industrial sediments in 275 lakes in alpine and arctic lake districts across Europe including the Pyrenees, Alps, the Rila Mountains, Retezat, Julian Alps, Tatras, Scottish mountains, Central Norway and Greenland (Camarero et al. 2009). They conclude: "In general terms, the increase in trace elements in modern with respect to

pre-industrial sediments reflects the history of a long range contamination affecting the remotest locations in Europe." A methodological survey of the existing techniques for detection, quantification, physical and chemical analysis of biological particles is presented by Georgakopoulos et al. (2009).

In a commentary article in Science about a paper of Priscu et al. (1998) "Perennial antarctic lake ice: an oasis for life in a polar desert", Psenner and Sattler (1998) compare the newly observed occurrence of microbial communities in "water pockets" in "slush ice" in some meters depth during austral summer with microbial life in snow layers of high alpine lakes. They state:

"A comparison of freshwater ice systems (...) suggests that the example described by Priscu et al. represents the most extreme community one can imagine, both regarding physico-chemical factors and organisms involved; namely, an assemblage of autotrophic cyanobacteria (blue-green algae) and heterotrophic bacteria, encapsulated in the permanent ice cover of lakes. The term "oasis" used by the authors" (Priscu et al. 1998) "refers to the fact that pockets of liquid water form around dust particles and microorganisms blown in from a cold desert, allowing active growth and reproduction of predominantly prokaryotic organisms during the Austral summer."

In that instance microorganisms are not only transported as aerosols, but they also obtain nutrients from aerosol particles and, being enclosed in ice, the particles' ability of sunlight absorption provides opportunity for liquid water formation in Antarctic summer sunlight, so much needed for any life processes. Psenner and Sattler (1998) further state: "The vision of a cold origin of life may lay the foundation for a model of past conditions on Mars and of present-day conditions on Europa".

In a pioneering paper Sattler et al. (2001) showed that bacteria isolated from supercooled droplets at 3 km elevation duplicate at a similar rate as bacteria in temperate freshwater lakes. They concluded that clouds do not act as conveyors of microbes, but support actively reproduction of microbial life due to the presence of nutrients, acting as a habitat and seeders of life (Sattler et al. 2002a, b).

The studies were extended to the colder climate of Antarctica, where "it has become evident that much of the microbial life within remote environments is transported by air currents" (Pearce et al. 2009). They summarize that many microbial genera commonly encountered in air samples were also found in the Antarctic by various groups, bacterial genera found in both environments included for example *Staphylococcus*, *Bacillus* and *Corynebacterium*, among

fungus genera *Penicillium*, *Aspergillus* and *Cladosporium* were observed. There is also evidence of microbes living in Antarctic "slush" habitats. Similarly to the Alpine situation microbial life forms were studied in Antarctic cryoconites (Foreman et al. 2007) and glacial discharges (Mikucki et al. 2004, Mindl et al. 2007).

The observation of proteobacterial strains in very cold as well as in very hot environments led to the hypothesis, that primitive life forms may have developed in extraterrestrial cold environments e.g. at Mars or at Titan. For a mission of probing the surface crust for the existence of prebiotic or microbiological tracers a suitable in-situ method had to be developed. Such a method, based on the exemplary work of Pinnick et al. (1995) of a fluorescence particle counter for detecting airborne bacteria and other biological particles aiming at detecting biological warfare species is currently tested for identifying microbial or prebiotic material on a Mars mission (Storrie-Lombardi et al. 2009a). The ExoMars mission is scheduled for 2016 with a primary goal of surveying the Martian subsurface for evidence of polycyclic aromatic hydrocarbons and other organic material. A test of the laser induced fluorescence excitation technique (L.I.F.E.) has been performed for in situ nondestructive detection of microbial life in the ice covers of Antarctic lakes (Storrie-Lombardi et al. 2009b). The authors conclude: "L.I.F.E. survey strategies described may be of interest for orbital monitoring of photosynthetic primary productivity in polar and alpine glaciers, ice sheets, snow, and lake ice of Earth's cryosphere. The findings open up the possibility of searching from either a rover or from orbit for signs of life in the polar regions of Mars and the frozen regions of exoplanets in neighboring star systems." A review on this issue is given by Sattler and Storrie-Lombardi (2010). An intriguing problem of the search for prebiotic or microbiological features on other planets is the prevention of biological contamination from the explorers. Microbes or related material may adhere on the astronauts' coveralls. Groemer et al. (2011) report about methods for reducing potential contamination of the astronauts' suits from microbes using the L.I.F.E. technique.

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Aerosol Scavenging Experiments

Anne Kasper-Giebl

1. Introduction

The term 'scavenging' summarizes all processes that lead to the incorporation of aerosol particles or gaseous compounds into the liquid phase (i.e. either into cloud, fog or rain droplets). Scavenging processes can take place either in-cloud or below-cloud.

Nucleation scavenging is the most important process of aerosol scavenging, as droplet formation itself is closely linked to the presence of aerosol particles in the atmosphere - *'without the dust particles in the atmosphere there will be no haze, no fog, no clouds and therefore probably no rain'* (John Aitken, as cited by Pruppacher and Klett 1998). At water vapour supersaturation ranging from less than 0.1% up to approximately 1% the condensation of water vapor occurs on aerosol particles, the so-called cloud condensation nuclei (CCN). The ability of an aerosol particle to act as a cloud condensation nucleus strongly depends on its size and its chemistry. Furthermore collision and coalescence contribute to aerosol scavenging processes.

The incorporation of trace gases into droplets is called gas-phase scavenging. Eventually chemical reactions and transformations in the liquid phase follow this process (i.e. reactive gas phase scavenging). Most of the droplets evaporate again and release processed aerosol particles, which are aerosol particles modified in size and chemistry.

2. Scavenging experiments

Investigations of the phase partitioning of trace gases in fog and clouds by Austrian groups started during the GCE (Ground based Cloud Experiment) project (Facchini et al. 1992, Winiwarter et al. 1994).

Scavenging experiments at high elevation sites were carried out at Sonnblick (3106 m a.s.l.) and Rax (1640 m a.s.l.). These investigations were initiated already in 1991 within the EUROTRAC project ALPTRAC (Alpine Transport of Air Constituents), which comprised in-cloud scavenging experiments as well as an alpine wide snow sampling program and thus allowed to link the process oriented scavenging studies to the ongoing deposition monitoring (Winiwarter et al. 1998). Starting with inorganic species organic aerosols were included in the program reflecting the growing interest on the ability of these aerosol compounds to act as cloud condensation nuclei (Novakov and Penner 1993).

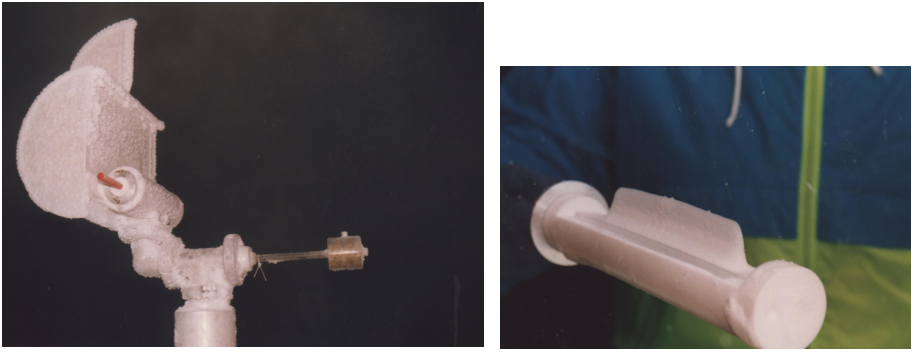


Figure 1: Cloud Water Sampling at the Sonnblick Observatory during the ALPTRAC campaigns showing the Cloud Water Sampler (Kruisz et al. 1993) and an actual sample of subcooled droplets.

Cloud water sampling and analysis

Early results within ALPTRAC included the development of a sampling method to conduct measurements in a cold cloud, i.e. to sample subcooled cloud water droplets as seen in Figure 1 (Kruisz et al. 1993), the determinations and calculations of the phase distribution of pollutants between the gas phase and the liquid droplets (Brantner et al. 1994, Winiwarter et al. 1992) and investigations on the degree of riming (Kalina and Puxbaum 1994). The investigations on cloud water chemistry and physical properties were later extended to organic material (Hitzenberger et al. 2002, Kasper-Giebl 2002, Löflund et al. 2002).

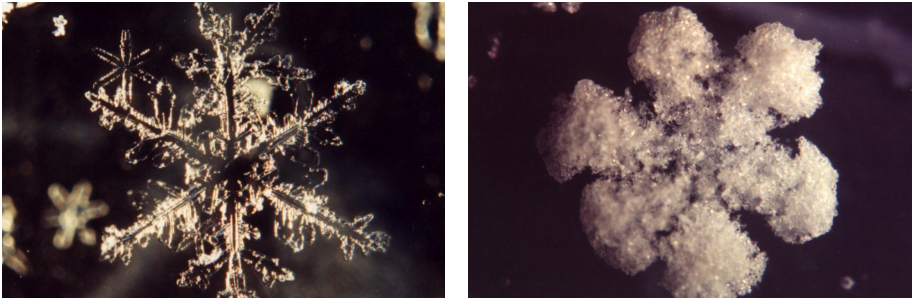


Figure 2: Ice crystal replicas prepared during the field campaigns at Sonnblick (Kalina and Puxbaum 1994).

Scavenging ratios

The scavenging ratio is the simplest approach to account for the overall scavenging process by relating air to liquid concentrations. At the Sonnblick Observatory scavenging ratios could be determined based on measurements performed at cloud level and thus were not influenced by different vertical profiles of aerosol concentrations and concentrations in wet deposition, respectively.

The simultaneous determination of aerosol species and trace gases (Kasper and Puxbaum 1998) furthermore allowed to determine the relative contribution of aerosol and trace gas species to total nitrate, sulfate and ammonium in precipitation (Kasper-Giebl et al. 1999). More recent results are given in Effenberger (2008) and Cerqueira et al. (2010) covering also scavenging ratios on organic compounds.

Scavenging efficiencies

The scavenging efficiency quantifies the fraction of a pollutant incorporated into cloud water droplets and thus quantifies in-cloud scavenging processes only. Based on the approach of Daum et al. (1984) and Dutkiewicz et al. (1995) the scavenging efficiencies for sulfate and lead were quantified and showed a strong dependency of the efficiencies on the liquid water content (LWC) of the cloud, but not on the total concentration values (Kasper et al. 1998).

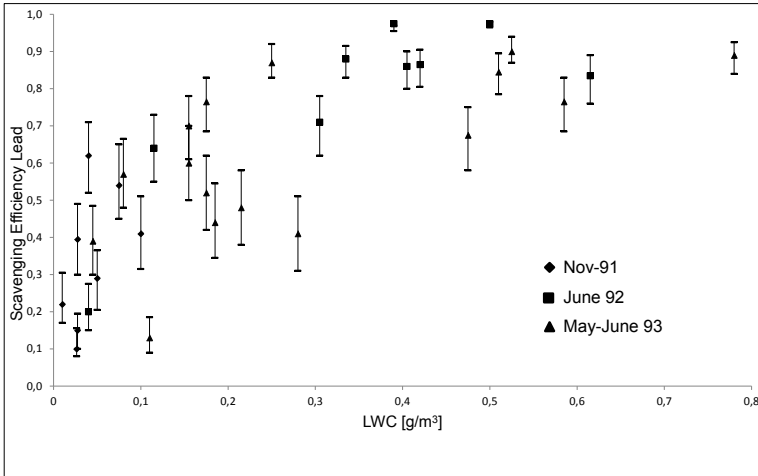


Figure 3: Scavenging Efficiency of lead determined at Sonnblick Observatory (Kasper et al. 1998).

Reflecting the growing interest on organic aerosols scavenging efficiencies were also determined for aerosol carbon (Kasper-Giebl et al. 2000), black carbon (Hitzenberger et al. 1999, Hitzenberger et al. 2001), total carbon (Hitzenberger et al. 2000) or for single organic compounds (Gröllert and Puxbaum 2000, Limbeck and Puxbaum 2000). The surface tension of cloud water was found to depend on its organic carbon content (Hitzenberger et al. 2002). Although being scavenged less efficiently than sulphate, black carbon is scavenged substantially and other more hydrophilic compound classes or compounds showed higher values up to nearly quantitative scavenging. This again emphasizes the importance of organic material in cloud processes. The dependency

on the LWC was observed for all studies. These investigations also led to the development of a gas and aerosol monitoring system (Löflund et al. 2001).

Bioaerosols

The concentration levels of organics determined in cloud water droplets led to research about the presence and viability of microorganisms in cloud droplets (Sattler et al. 2001) showing that cloud droplets form a habitat for bacteria to survive and grow. Further research on bioaerosols in respect to scavenging behaviour comprises the distribution of bacteria and fungal spores in cloud water, precipitation and aerosols (Bauer et al. 2002) and the ability of bacteria to act as cloud condensation nuclei (Bauer et al. 2003). More information about bioaerosols is given in this compendium, pp. 47 ff.

Determination of cloud condensation nuclei

Other investigations on the behaviour of single compounds as cloud condensation nuclei using a cloud condensation counter developed at the University of Vienna comprised lab experiments on selected organic acids (Giebl et al. 2002) and pure and coated carbon black particles (Dusek et al. 2006) as well as properties of jet engine combustion particles (Hitzenberger et al. 2003, Gysel et al. 2003).

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Time series of correlation coefficients of atmospheric PM

Axel Berner, Regina Hitzengerger

1. Overview

A new application of the correlation coefficient to atmospheric PM data, developed under the AUPHEP project of the Clean Air Commission (see this compendium, pp. 130 ff), has been presented by Berner et al. (2004).

While traditional use of correlation coefficients will apply the method to a complete data set, the correlation coefficient can also be calculated for subsets of data. Here a window of only a few, three or more subsequent data points are selected out of time series, e.g. of 12h PM concentrations measured by cascade impactors. Moving this time window over a series of data yields a time series of short-term correlation coefficients (Figure 1). These coefficients as a function of time can be called a correlation function, $R(t;w)$. This function depends to some degree on the size of the window, w . The method can be applied to time series of different PM parameters measured at a single station or to time series measured at several stations that may be separated by distances of several tens of kilometers or more.

First results obtained for PM series at two stations (Berner et al. 2004) are surprising (see Figure 1). In PM₁₀, periods of time with highly positive correlation are interrupted by minima of short duration and also by periods of neutral or negative correlation. Similar structures occur in PM_{2,5}, and in other seasons (Berner et al. 2004). They also occur in the data of other PM instrumentation, and are therefore of more general character. At present these structures are only partially understood, though it is safe to say:

- Minima of short duration, like those on 24.1.2000 (14:00), 28.1.2000 (2:00) and 31.1.2000 (2:00) (figure 1), are related to changes of the weather situation
- The linear regressions of PM, belonging to time periods enclosed by such minima, differ. Therefore the weather related minima separate different PM regressions
- In some respect this result already underlines the usefulness of correlation functions $R(t;w)$
- Periods of neutral or negative correlation indicate other situations. Investigations into the reasons, among them strong effects of local sources at a sampling site, can be concentrated on well defined periods of time, as indicated by the correlation function

- Strong effects of local sources at both sampling sites can lead to very high correlation coefficients running up close to unity for some time

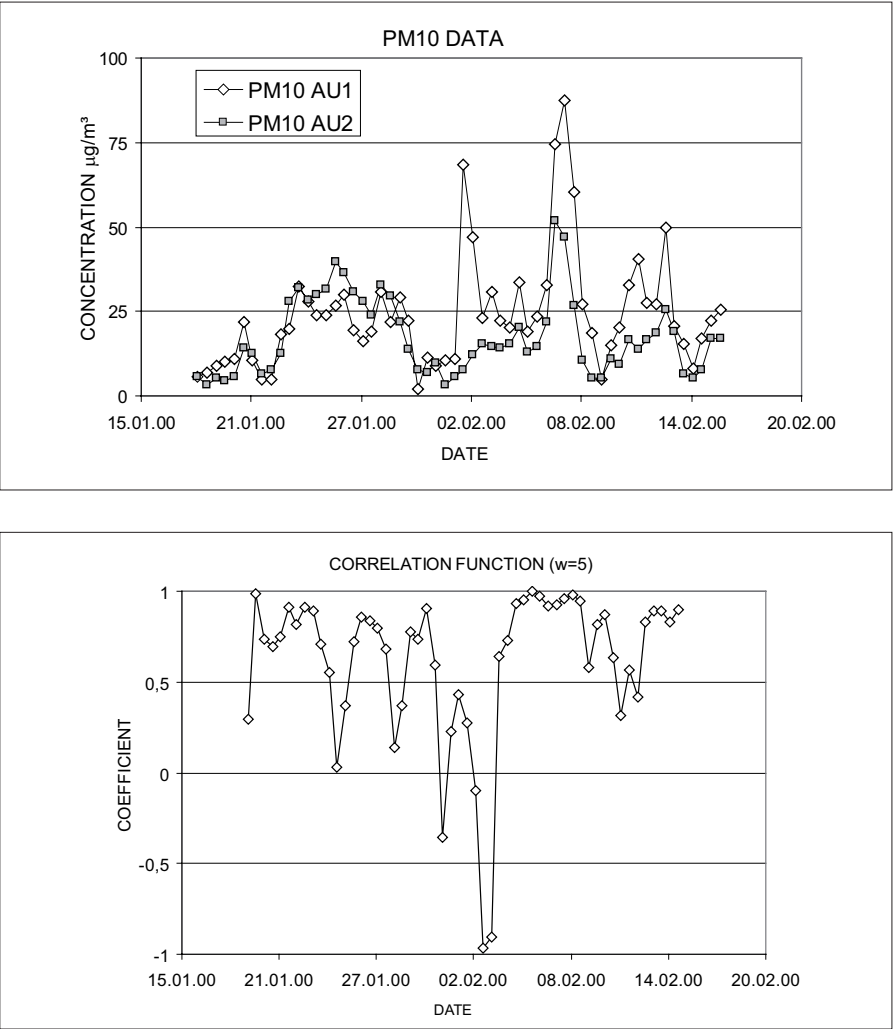


Figure 1. PM10 concentrations at two sampling sites, AU1 and AU2 of the AUPHEP project, together with their correlation function, $R(t;5)$. This function has been calculated for five subsequent pairs of data points of the PM10 time series.

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Dispersion modelling

Peter J. Sturm, Christian Kurz, Gerhard Bachler

1. Background

In many regions in Austria the topographical situation and the meteorological conditions result in high PM₁₀ concentration values. The reasons of the high PM₁₀ burden are various. Local and regional emissions combined with unfavourable dispersion conditions are of importance in some regions, while in other the transboundary pollution, mainly from central Europe (east and south-east), is the decisive factor. In addition the basins in the central Alps as well as on the south side of the Alps suffer from unfavourable dispersion conditions with low winds, strong inversions during wintertime and little precipitation.

In order to elaborate and furthermore evaluate the effects of action plans before they are set into force the contributions of different sources has to be known. Therefore a combined emission-dispersion tool has been developed and applied to certain regions in Austria. When looking on emission inventories very often it turns out that traffic, domestic heating and industry contribute equally to the PM₁₀ problem. If dispersion is taken into account, widely distributed low level sources like domestic heating become the major source. In countries like Austria with an intensive road service during wintertime due to de-icing and sanding, this winter service might also be a major source of air pollution.

As PM₁₀ emissions have various sources an abatement programme has to consider the impact of all these possible sources. But this implies that the sources are known, i.e. necessity of a good emission inventory and the impact can be determined, i.e. dispersion calculation.

2. Methodological approach

The approach for evaluating the impact of different sources on the air quality as well as that of quantifying the effects of some abatement measures is based on the application of a high level emission inventory combined with a dispersion model.

Emission inventory

The emission inventory is the basis for all the quantification activities. Hence, it is imperative, that a high quality in source description is required. This high quality concerns quantification as well as temporal and special allocation.

Dispersion modelling

For dispersion modeling the model system GRAL, a Lagrange particle model, which has been developed at the Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology, is used. This model system accounts especially for calm wind conditions, which are dominant in Alpine basins like the Graz or the Klagenfurt basin.

The model system consists mainly of two modules:

- The non-hydrostatic prognostic wind field model GRAMM used for analysing stationary wind fields serving for the pollution dispersion in complex terrain or in build up areas.
- The dispersion model GRAL developed for the specific dispersion situations both in calm wind conditions (the occurrence of large horizontal eddies) and from tunnel portals (effect of the jet streams).

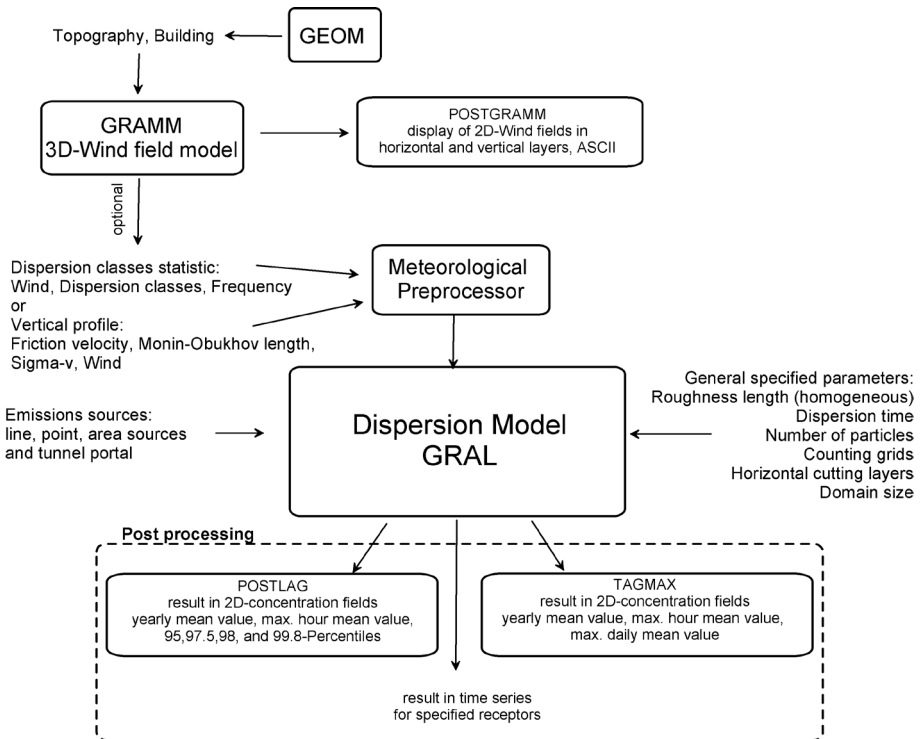


Figure 1: The model system.

Figure 1 depicts an overview of the models system. The module GEOM provides the terrain data for the wind field and for the dispersion simulations. GRAMM calculates the 3-dimensional wind fields. Turbulence parameters such as Monin-Obukhov length, friction velocity and so on are either provided by appropriate observations or are estimated by the meteorological pre-processor.

GRAMM

The analysis of wind fields with GRAMM (Almbauer et al. 2000, Oettl 2000) offers the advantage, in comparison to diagnostic wind field models, to take into account dynamic effects (e.g. obstacle influenced flows). Therefore the model is initialized with a horizontally homogenous wind field and then the steady-state wind field is computed by solving the Navier-Stokes equations (RANS). This is the common way of computing topography influenced flows in the microscale (Schaedler et al. 1996). For the initialization the data from a local observation of wind speed, wind direction and a kind of atmospheric "stability" (e.g. radiation balance, cloud amount) are used. Due to this limited number of required input parameters it is possible to establish a simple classification of the meteorological conditions. The main disadvantage of this method is that often measurements, representative for the large scale wind (e.g. the mountain/valley breeze), are not available. In this study representative meteorological wind stations in both basins were available.

As locally observed wind directions and speeds are used as input to the model, the main characteristics of the pollutant advection is already captured (frequency distribution of wind speed, wind direction). The main assumption is that all other parameters in a mesoscale model are of minor importance once the large scale wind is used as input. The subsequent computation of a steady-state flow field for each classified meteorological condition using constant boundary conditions derived from the locally observed large scale wind aims mainly at the simulation of very local topographical influences on the large scale wind (e.g. development of eddies in the wake of mountains).

GRAL

Dispersion modelling is carried out using the model Lagrangian Particle Model GRAL (Oettl et al. 2001a) which is initialized with the steady-state wind fields calculated by GRAMM. During low wind speed conditions large horizontal atmospheric motions develop (so called meandering), which influence the dispersion process significantly. Lagrangian models like GRAL are less affected by the problems of Gauss models, which produce unrealistic high results for very low wind speeds. Nevertheless a special parameterisation of the

necessary turbulence parameters for low-wind situations is required. When the parameters for higher wind speeds are used, it basically results in excessive pollution concentrations. The reason for this is that low-wind situations are frequently connected with considerable changes of the wind direction and a completely changed dynamics concerning the pollutant dispersion. This leads to faster dilution of air pollutants. The Lagrangian model used applies an algorithm created especially for this problem (Oettl et al. 2001a). It considers the effect of stronger turbulences in low-wind weather situations, which was also found in tracer gas experiments.

The input data from the emission inventory consists of different source types with different release characteristics. As a consequence it is necessary to simulate these different kinds of sources like line sources, point sources and tunnel portals, simultaneously. GRAL achieves for these requirements and the following parameters are taken into account for the individual source types:

- Point sources: location (3D): Source strength, exit velocity, temperature differences, and diameter
- Line sources: location (3D, also bridges): Widths, source strengths, heights of noise barriers
- Area sources: Same as line sources
- Tunnel portals: Location (3D), source strengths, exit velocity, temperature differences, traffic influence on tunnel jet

The dispersion of pollutants from longitudinal ventilated tunnels is considered to differ significantly from those of other sources, such as line or point sources. In order to take all the peculiarities of the dispersion from tunnel portals into account a special software module (GRAL TM 3.5) has been developed.

Near the tunnel portal differences in temperature and velocity between the tunnel air and the ambient air occur. For vertical dispersion a modified method according to van Dop (1993) for point sources is utilized, which is able to account for buoyant plumes (i.e. when there exist positive temperature differences).

The impact of the tunnel jet stream on dispersion is caused by two main forces:

- Turbulent friction due to differences in the velocity of the ambient wind parallel to the jet stream and the jet stream which causes it to slow down
- A pressure force caused by the ambient wind perpendicular to the jet stream which bends the jet stream towards the ambient wind direction

The module accounts for wind direction fluctuations, which cause the tunnel jet also to vary in space.

GRAL TM 3.5 has been tested against five data sets from different tunnel portals in complex and flat terrain with different meteorological conditions (high/low wind velocities, stable/unstable atmospheric conditions).

Quality assurance

The wind field model GRAMM has been validated (Oettl 2000) and its performance has been evaluated by applying it in the MESOCOM (Thunis et al. 2003) and DATE-Graz projects (Almbauer et al. 2000).

The quality assurance of the modelling system GRAL is mainly based on the comparison of observed and modelled concentrations for certain field experiments. Currently 18 different data sets for tunnel portals, point sources, line sources and built-up area are used for the model evaluation, such as Prairie Grass, Indianapolis, INEL, Elimaeki, Goettingerstrasse, Hornsgatan, etc. Many of the modelling results have been published in peer-reviewed journals (Oettl et al. 2001b, Oettl et al. 2003).

3. PM source contributions

3.1. Application to the city of Klagenfurt

This approach has been applied to the city of Klagenfurt, which is a city of 90.000 inhabitants and some 150.000 including the suburbs and commuters. Its location in a basin on the south side of the Alps result in wintertime in long periods with strong inversions combined with calm winds. These unfavourable dispersion conditions lead to a relatively high PM₁₀ burden. The annual mean values are met on all air quality monitoring locations, but the threshold value for PM₁₀ as daily mean value is exceeded frequently. In 2005 85 violations were registered at one of the monitoring stations (see Table 1).

In the framework of the EU-Life project KAPA-GS (Sturm et al. 2007) an intensive study was carried out to determine the share of different PM₁₀ emission sources. Measurements were combined with numerical simulations and chemical analyses. On one hand the numerical simulations – based on emission inventories and dispersion calculations – allow for a clear distinction between the different sources. On the other hand the chemical analyses of PM₁₀ samples allow for a source profile on the measurement side and for a validation of the model chain. Figure 2 shows the area under investigation. This area covers some 10 by 10 km.

Table 1: PM10 concentrations during the years 2000 to 2005.

Air quality monitoring station		max. daily mean value ($\mu\text{g}/\text{m}^3$)	No. of days > 50 ($\mu\text{g}/\text{m}^3$)	annual mean value ($\mu\text{g}/\text{m}^3$)
Koschatstrasse (urban background)	2005	86	31	26
	2004	84	34	27
Völkermarkterstrasse (hot spot location)	2005	123	84	39
	2004	116	80	38
	2003	99	74	38
	2002	127	58	37

Figure 2: Satellite image of the city of Klagenfurt (<http://www.klagenfurt.at/inhalt/873.htm>).

Current situation

The emission situation is given on bases of an emission inventory, which is updated on an irregularly bases. The latest update was made in 2004 and covered the sectors 'traffic' and 'domestic heating'. Emissions for the sector 'trade and industry' are currently available only on basis of 1999 data. Figure 3 shows the calculated emissions for the city of Klagenfurt.

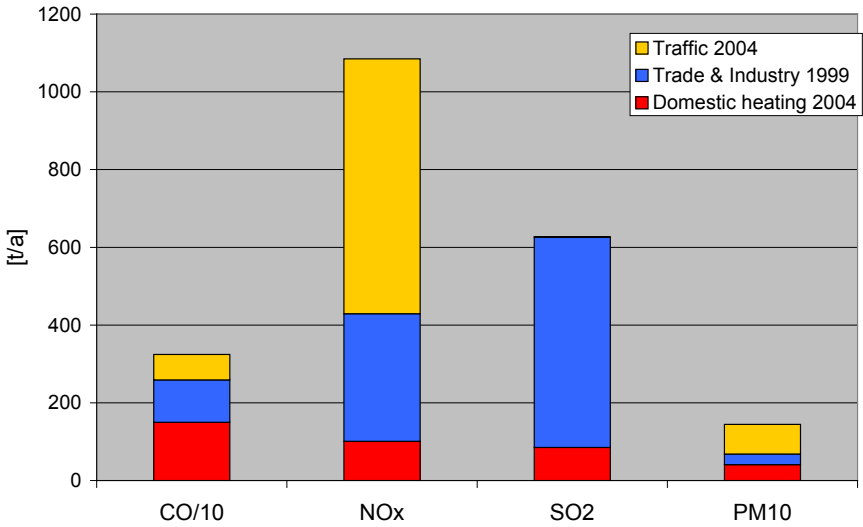


Figure 3: Emissions for the sectors 'traffic', 'trade & industry' and 'domestic heating'.

Traffic emissions were calculated as line sources (hot exhaust emissions and resuspension of road dust), using traffic data on road by road basis, and as area sources (cold start emissions), based on demographical data. Domestic heating emissions were calculated on basis of statistical data given for special demographical areas using data on fuel usage, heating systems and building structure. Data for trade and industry is based on single inquiries (big point sources) and statistical data using either fuel usage or production information.

When considering road traffic, strong emphasis was put on the influence of winter service. During wintertime road sanding or de-icing (salt) is a major source of PM10 pollution. Detailed investigations led to the development of site-specific emission factors for resuspension of road dust (Sturm et al. 2007).

Figure 4 show the emission factors derived from roadside measurements over one year. The peak value for TSP in March was due to intensive road cleaning during that time. However, the peak was monitored for TSP but not for the PM10 fraction.

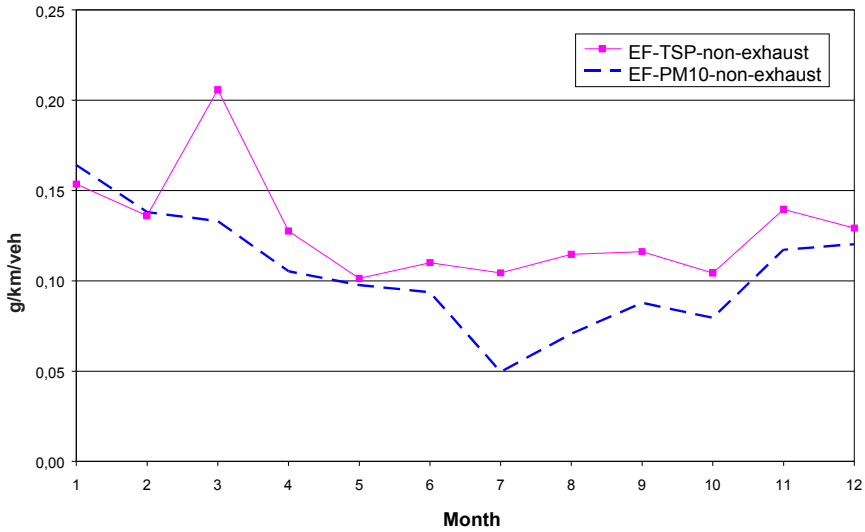


Figure 4: Emission factors for TSP and PM10 non-exhaust emissions.

Combining emissions with dispersion modelling resulted in source related figures concerning PM10 pollution. Figure 5 to Figure 8 show the results for various sources. While PM10 from traffic exhaust follows strongly the roads with heavy traffic, traffic non-exhaust PM10 emissions have a broader dispersion band. This is mainly due to the higher quantity of non-exhaust PM10 and due to different emission factors for de-icing (salting) on the main routes and sanding in the secondary road network.

Domestic heating has the biggest extension in terms of covered area. The highest local contributions result from traffic and domestic heating.

However, taking all these sources into account only some 50% of the measured values can be attributed to contribution of the modelled sources. I.e., a big share of the total PM10 burden is missing. This has two reasons. One of them is the share of secondary formed particles, the other one is the part of the background concentration, i.e. that pollution which is transported into the calculation domain.

The calculated concentrations were compared to the values derived from the both monitoring stations 'Völkermarkter Straße' (kerbside location) and 'Koschatstraße' (urban background location). Based on these calculations, background and secondary formed PM10 pollution account for some 15 to 20 $\mu\text{g}/\text{m}^3$ (annual mean value).

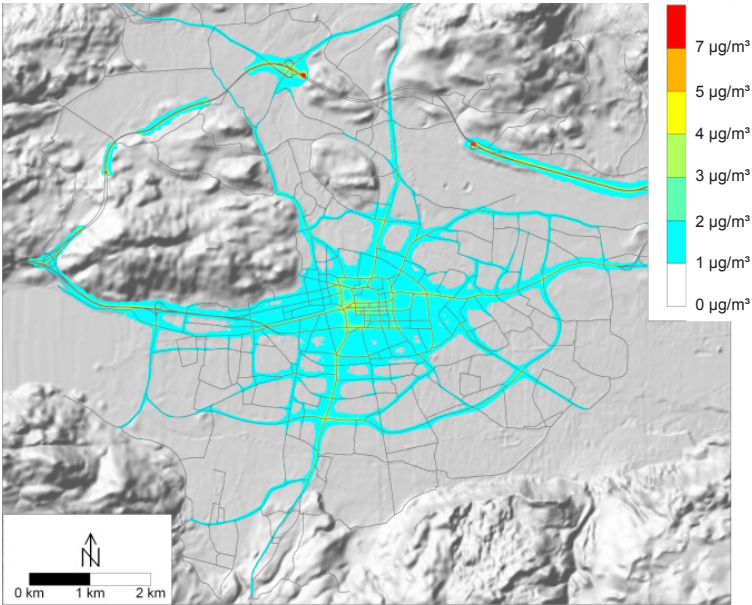


Figure 5: Contribution of traffic related exhaust emissions to the PM10 annual mean concentrations.

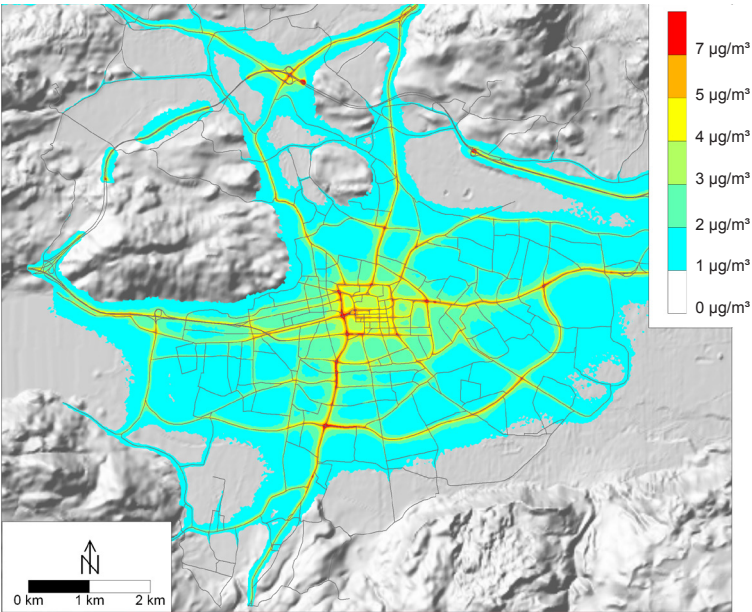


Figure 6: Contribution of traffic related non-exhaust emissions to the PM10 annual mean concentrations.

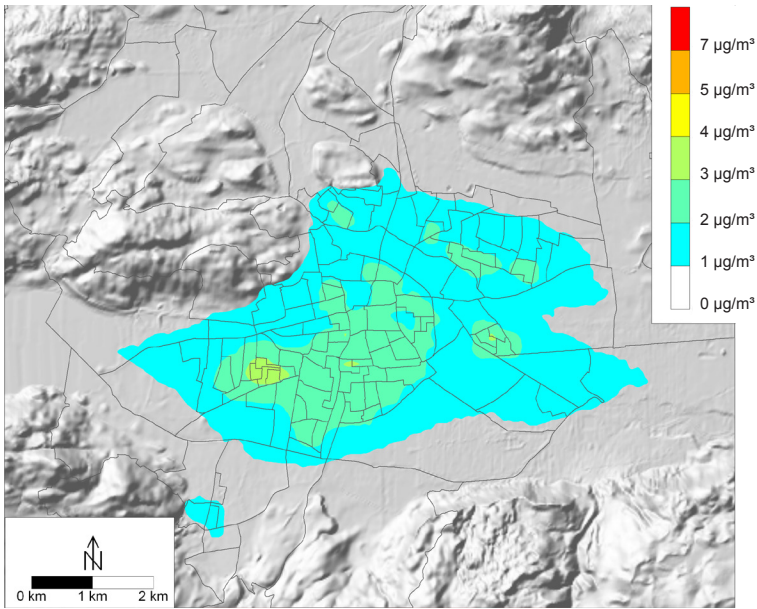


Figure 7: Contribution of 'trade & industry' emissions to the PM10 annual mean concentrations.

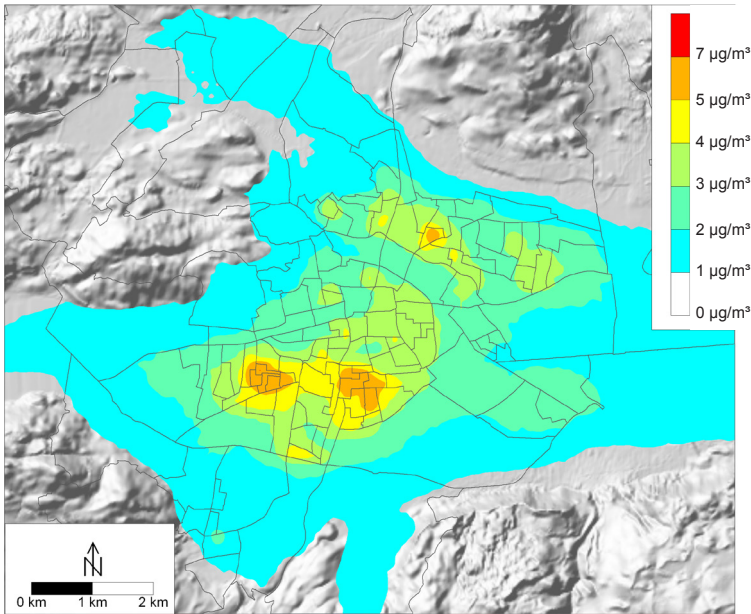


Figure 8: Contribution of 'domestic heating' emissions to the PM10 annual mean concentrations.

Figure 9 shows the total PM10 concentrations (annual mean value). The main roads and the city centre are the most polluted parts. In addition one region with a high share of solid fuels (wood and coal burning) is clearly depicted in the south and south west of the region.

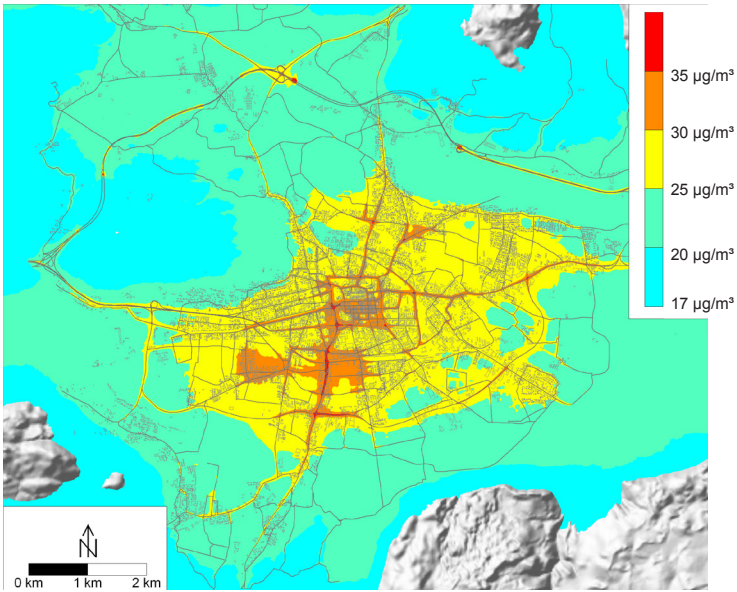


Figure 9: PM10 annual mean concentrations.

Figure 10 depicts the shares of the different source types at the kerbside monitoring location 'Völkermarkter Straße'. Shown is the average over the winter months November to March. As to be expected the non-exhaust part is dominating (winter service). But even at that location domestic heating contribute more to the pollution than traffic exhaust emissions.

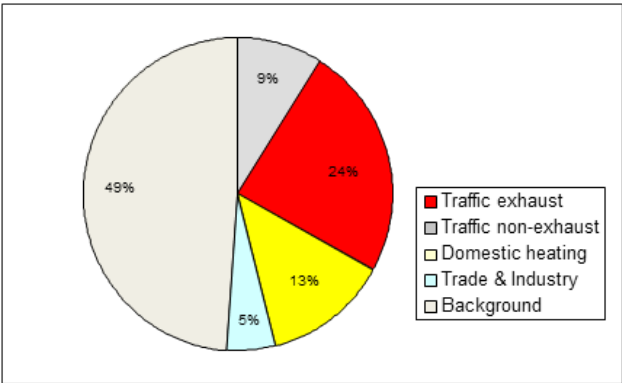


Figure 10: Calculated PM10 winter mean concentrations at the monitoring location 'Völkermarkter Straße', share of the different source types.

3.2. Application to the Lavanttal region

The Lavanttal region is a basin with an extension of some 30 times 20 km (see Figure 11). The mountains in the east, north and west reaches altitudes between 1800 and 2200 m asl., while the basin is at an altitude of 400 m asl. The hills in the south reach up to some 800 m asl. Major emitters in that region are a paper and pulp mill, the small town of Wolfsberg and agricultural activities. Traffic is dominated by a highway and some minor roads.

Current situation

Besides two big industrial facilities (pulp and paper mill and wood industry) this region is mainly dominated by small enterprises and agricultural activities.



Figure 11: Topographical map of the Lavanttal basin.

Nevertheless, PM10 is a problem. While there is no problem in meeting the AQ standard for the annual mean value, the 50 $\mu\text{g}/\text{m}^3$ threshold for the daily mean value is violated throughout the whole basin between 35 and 68 days per year. Due to this, a detailed emission analyses was performed. Contrary to urban locations in this case emissions from farming play an important role. On basis of the available data only emissions from land cultivation (e.g. ploughing, harrowing) were taken into consideration, emissions from life stock were excluded. Figure 12 shows the contributions of the different source categories. Farming is dominating.

although it has to be considered that these emissions occur mostly during the 'low pollution season' spring to autumn. Industry has also a remarkable share. However, those emissions are discharged with high stacks and hence

contribute only little to the low level concentrations. Domestic heating has a relatively high share as in the rural areas wood is still a major energy source. In future this wood burning might become even more popular due to its positive effects on greenhouse gas emissions. Concerning road traffic, exhaust and non-exhaust PM emissions are in the same order of magnitude. During wintertime traffic non-exhaust is by a factor of three to four more important than traffic exhaust.

Applying the dispersion calculations the contributions from the different source types to the overall PM10 concentrations can be determined. Figure 13 to Figure 16 contain now the contributions from the different source types to the PM10 concentrations (annual mean value). Farming and domestic heating has the greatest impact in terms of area coverage. As stated above, the farming contributions are mainly during spring to autumn, while domestic heating is typically a winter time problem.

Figure 17 contains all source contributions including background concentrations. As in all other investigations, background account for almost 50% of the measured PM concentrations. This background consists again of secondary formed PM and primary PM transported into the calculation domain. In this case background was determined by measurements taken from a monitoring station within the calculation domain, but at a higher altitude location. The annual mean value at that station amounts to $17 \mu\text{g}/\text{m}^3$. Adding this value to the calculated ones results in a good agreement between calculation and measurement at the remaining three monitoring locations.

There is a strong correlation between annual mean values and days of violations of the $50 \mu\text{g}/\text{m}^3$ for the daily mean value. This correlation can be defined according to the following equation.

$$\text{Number of days exceeding } 50 \mu\text{g}/\text{m}^3 = 4 \text{ times annual mean value} - 77$$

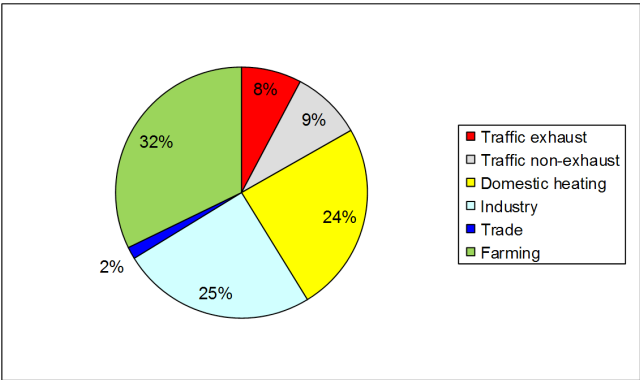


Figure 12: Contribution of the different sources to the PM emissions in the region under consideration.

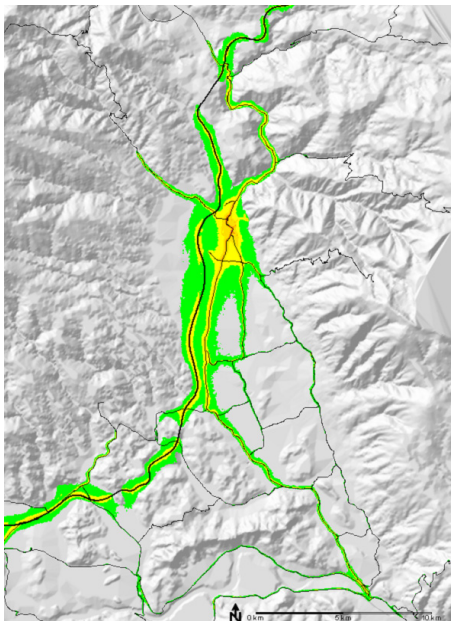


Figure 13: Road traffic related PM10 concentrations.

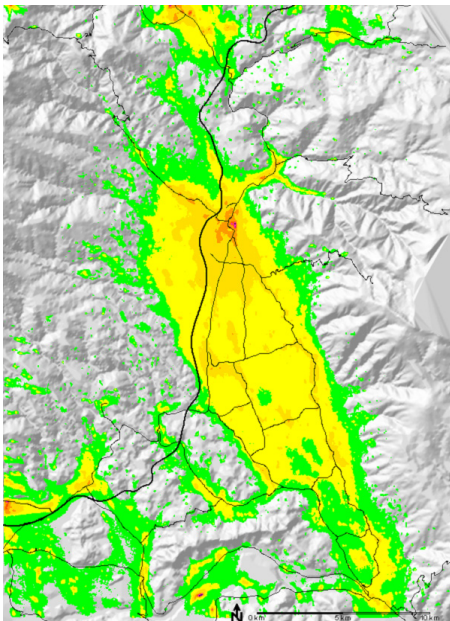


Figure 14: Domestic heating related PM10 concentrations.

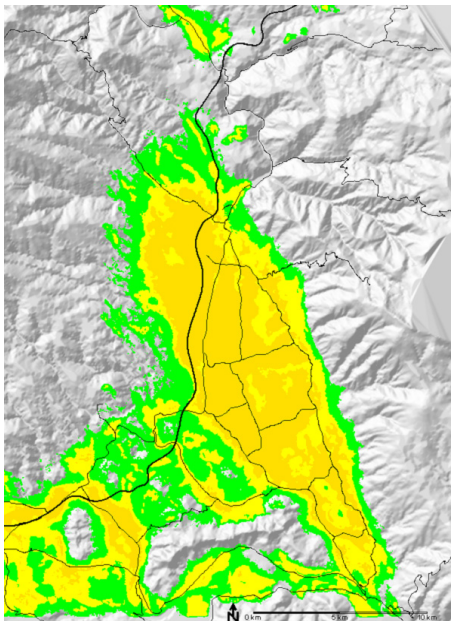


Figure 15: Farming related PM10 concentrations.

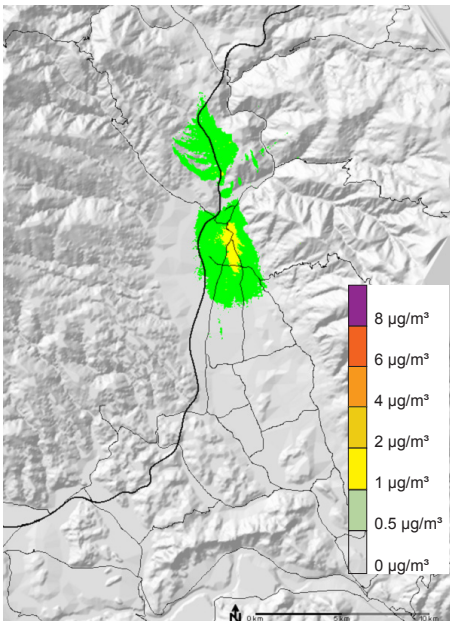


Figure 16: Trade and industry related PM10 concentrations.

The area inside the thick blue line in Figure 17 depicts the region in which the Austrian PM10 standard for 2010 (25 days with exceedances) will be violated. Such areas have to be declared as PM10 non-attainment zones. In such zones abatement measures have to be set by law.

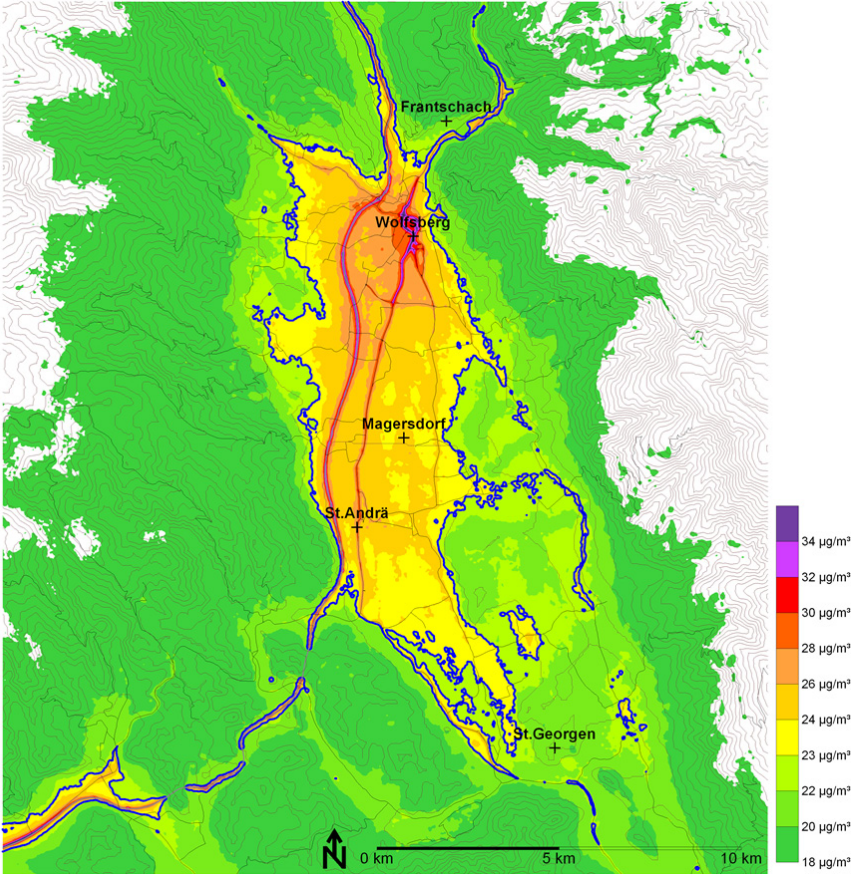


Figure 17: PM10 concentrations, all sources, annual mean.

4. Summary

PM10 remains to be a major problem in air quality. At most monitoring locations the annual mean value can be met without problems, but the threshold for the daily mean value is exceeded frequently. In most cases it is a combination of local emissions, background emissions and unfavourable dispersion conditions which might result even in small agglomerations in threshold violations. As a result of this many regions in Austria had to be assigned as

non-attainment regions, even in small agglomerations. In those regions action plans have to be implemented in order to archive the air quality goals.

The combination of emission inventories with dispersion tools allows for a detailed analysis of the causes of PM₁₀ problems. Moreover the definition and evaluation of PM₁₀ abatement plans is strongly related to such tools.

However, it has to be kept in mind, that the regional background concentrations as well as the formation of secondary aerosols (nitrates and sulphates) play a major role in the PM₁₀ problem. The contribution of both these "fractions" can only be taken into account as background contribution.

The methodology described here has already been applied to many cities and regions of Austria and abroad and is basis for defining and evaluation of abatement plans.

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Aerosol source-receptor studies

Hans Puxbaum

1. Overview

Dispersion models are based on source emission data and prediction of ambient concentrations making use of meteorological dispersion parameters. Conversely, source receptor models are based on a detailed knowledge of the chemical composition of the ambient aerosol and retrieval of the source impact by advanced statistical or refined tracer methods. The statistical methods make use of a series of ambient aerosol data and derive the source information by multivariate techniques such as PMF (Positive Matrix Factorisation). The tracer methods are based on knowledge of the typical source composition ("Source Profile" and derive the source information by a fitting procedure of sources from the ambient composition, designated as the "Chemical Mass Balance" (CMB). A related but simpler approach is the use of mass closure models, which make use of characteristic tracers for certain source categories. At Vienna University of Technology a mass closure model based on new characteristic tracers for major source categories was developed where most of the tracers are major components of the source profiles. This "Macro Tracer Model" was applied for a series of aerosol studies which are discussed in detail later in this chapter. The new tracers developed for the "Macro Tracer Model" comprised organic species such as cellulose – the main constituent in green plants (Kunit and Puxbaum 1996, Puxbaum and Tenze-Kunit 2003); "HULIS" ("humic like substances"), a predominantly secondary organic aerosol component (Limbeck et al. 2005); bacteria and fungal spores, the main components of the bio-aerosol (Bauer et al. 2002, Bauer et al. 2008) and levoglucosan, mannosan and galactosan, specific wood combustion tracers (Caseiro et al. 2007). Methods for the determination of the wood smoke tracers have been known before, however in the course of the macro tracer development it turned out, that in addition to the wood smoke tracers arabitol and mannitol were potent tracers for fungal spores and thus a specific method for the simultaneous determination of those tracers was desirable (Iinuma et al. 2009).

Also inorganic tracers were investigated: Si as main constituent of the mineralic aerosol (Peng et al. 2010) and platinum group elements as tracers for catalyst equipped automobile emissions (Limbeck et al. 2003). Finally, a method for carbonate, a missing component in the group of inorganic ions was introduced (Jankowski et al. 2008).

The Macro Tracer Method was applied in various forms in many international studies. Specific applications were for assessing the contribution of wood smoke to ambient PM levels (Puxbaum et al. 2007, Lanz et al. 2008, Sandrade-

wi et al. 2008, Pio et al. 2008). The formation of HULIS in smog chamber experiments was investigated in a study with the Paul Scherrer Institute (Baltensperger et al. 2008). The three main projects where the Macro Tracer Method has been applied (AUPHEP, CARBOSOL, AQUELLA) are discussed below; some of the data have also been used for the "European Aerosol Climatology" paper (Putaud et al. 2010).

In addition to these tracer methods, based on chemical analyses, source – receptor studies in Austria were also performed on purely meteorological methods. The trajectory statistics as developed by Scheifinger and Kaiser (2007) and used for gaseous pollutants by Kaiser (2009) found application in a number of studies performed for PM (e.g. Salvador et al. 2010, Offenthaler et al. 2009, Kaiser 2007). Results were also used with respect to health studies (Moshammer et al. 2009).

2. Mass balance studies

At an early stage of development mass balances were applied to derive information about major source impacts on the fine particles. A study in the savanna of South Africa was deployed to obtain information about the biogenic background component of the organic aerosol. Although situated at a background site considerable contributions from inorganic secondary aerosol (mainly sulfate) were observed. The main component in aerosol was soil dust (36%), followed by organic material (28%), and ammonium sulfate (27%). Aerosol humidity was 6%, BC 2% and plant debris 7%. A diurnal trend of the OC/EC ratio of 16 during day and 6 during night indicated a daytime source for organic components considered to originate from gas-particle conversion from biogenic emissions (Puxbaum et al. 2000).

The methods developed were also employed for aerosol studies in Bangladesh. The aerosol composition in the mega-city Dhaka was dominated by soil-type mineralic material, followed by carbonaceous material and ions (Salam et al. 2003a). From EC/OC relations and information from trace elements it was derived, that biomass combustion was not the dominant source for OC in the aerosol. Differences in the EC:TC and K:EC ratios in the 3 southeast Asia mega-cities (data available from Dhaka, Bangladesh; Lahore, Pakistan; Mumbai, India) indicated the aerosol source mix in southeast Asian cities varies considerably at national or even regional scales. A companion study at a background site in the Gulf of Bengal identified two different transport situations: In one period the EC/OC ratio was pointing to a predominantly fossil fuel dominated carbonaceous fraction in the aerosol; in the other period when the aerosol arrived from Indian coastal regions around 50% of the carbonaceous material was from biomass combustion (Salam et al. 2003b).

A further step, also based on mass balances was the TU Vienna contribution to the AUPHEP study (for a detailed presentation of the project see this compendium, pp. 130 ff). The gas and aerosol part was designed as a dual-site study with one site in the 9th district in Vienna, and one background site about 40 km upwind northwest of Vienna. Collocated PM_{2.5} and PM₁₀ samplers were used for collecting aerosol filters analyzed for carbonaceous material, ions, and trace metals. The PM_{2.5} and PM₁₀ measurements at the 2 sites indicated only low aerosol generation activity in the city on an annual basis. Defining the term urban impact as the difference between observations at an urban and a regional background site, an annually averaged urban impact for PM_{2.5} was 3.4 µg/m³ and for PMC was 3.3 µg/m³ (coarse fraction PMC = PM₁₀-PM_{2.5}). The relative increase of particulate matter (PM) concentration at the urban vs. background sites was annually averaged to be 19% for PM_{2.5} and 60% for PMC, indicating a relatively strong mineralic aerosol source in the city. Major chemical constituents of the PM_{2.5} urban impact were black carbon (BC), organic carbon (OC), and SO₄²⁻; main constituents of the PMC urban impact were OC and indicators for mineral aerosol (Fe, Ca, Mg, Na, K). The BC:TC ratio of PM_{2.5} urban impact was typical for combustion sources, e.g., automotive traffic, oil or coal combustion. Urban coarse OC was tentatively attributed to non-pyrogenic sources. From trace metals (As, Cd, Co, Cu, Cr, Mn, Ni, Pb, V, Zn), only Cd, Ni, Pb, and Zn exhibited a slight cold season enrichment in the urban airshed. From the weak seasonal signal for oil or coal combustion indicators, it was concluded that local domestic heating sources are using clean fuels (Puxbaum et al. 2004).

At this stage it became clear, that for a better understanding of the sources of the mineralic aerosol the main components Si and Al had to be included in the list of determined components. This request posed a considerable challenge for the sampling procedure, as the standard filter for chemical analysis was generally a pre-cleaned quartz-fibre filter. Thus, for the analysis of mineralic constituents a further sampler equipped with cellulosic filter material was applied, the filter being analysed by WLD-XRF (wavelength dispersive X-ray fluorescence) (Peng et al. 2010). From a half year data set from Goess (Styria) interesting details of the atmospheric occurrence of mineralic material emerged: Silicious material predominantly from crustal material, e.g. street abrasion, aeolian dust (analytical tracers Si, Al) showed in the temporal trends a decoupled behaviour from "carbonates" (analytical tracers soluble Ca, Mg). A decrease in Si and Al and an increase in carbonates, Na, K, Zn and P were observed during the cold season. Si and Al were highly correlated in all seasons with a Al/Si ratio of 0.27, identical with the respective ratio observed for the continental upper crust (Fig. 1a). Ca shows a wide variation in the relation to Si with a lower limit of Ca/Si 0.3, which is higher than the equivalent to the natural ratio in the upper crust (0.13). The Ca/Si ratio of 0.3 – dotted line in Fig. 1b – is considered to "represent" the street abrasion material (Fig. 1b). The in-

crease in variability and of absolute levels of carbonates during the cold season was most likely deriving from dolomite gritting material. A marked increase in winter was also observed for Na and Cl originating from the use of thaw salt. A winter increase of K, Zn and P pointed to domestic wood combustion as common source. PM10 levels were 12 $\mu\text{g}/\text{m}^3$ higher in December than in July, due to increased carbonates (gritting), thaw salt, wood smoke and inorganic secondary material, predominantly nitrates (Peng et al. 2010).

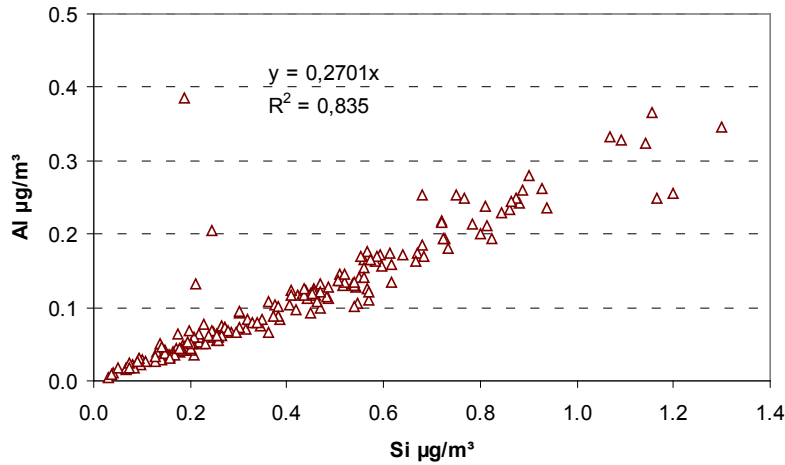


Figure 1a: Al and Si concentrations from the half year data set from Goess (Styria). (Data from July 2006–Jan 2007, from Peng et al. 2010).

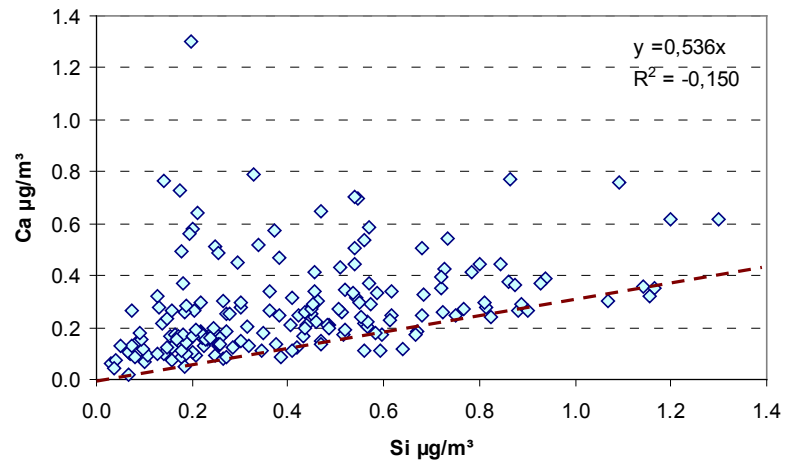


Figure 1b: Ca and Si concentrations from the half year data set from Goess (Styria). (Data from July 2006–Jan 2007, from Peng et al. 2010). The dashed line marks the Ca/Si ratio 0.31 considered the contribution of Ca from street abrasion.

Table 1: Macro-tracers used to derive source contributions, associated source groups and main sources.

Analyte	Source Group	Sources
Levoglucosan	Biomass-Smoke	Wood combustion (domestic) Wild fires, open fires
Arabitol	Primary Biological Particles	Fungal spores
HULIS (Humic Like Substances)	Organic Secondary Aerosol	Winter: Wood combustion Summer: natural Sources
Cellulose	Plant Debris / Detritus	Plant Debris
Soot (BC or EC)	Combustion	Diesel-Emissions Wood-Combustion Coal-Combustion Fuel Oil-Combustion
Si, Ca	Mineralic Dust	Street Abrasion Winter Sanding (Gravel) Sidewalk Sanding Construction Sites Dusty Vehicles Aeolian Dust
NaCl	Thaw Salt	Thaw Salt Sea Spray
Ammonium, Nitrate, Sulfate	Inorganic Secondary Aerosol	NH ₃ : Agriculture SO ₂ : Coal, Smelters NO _x : (Hot) Combustion
Unidentified		Further secondary OM Aerosol humidity

The results of the AQUELLA study are subject of reports to the country governments. Reports are available from the official information systems of the provinces Styria (Bauer et al. 2007a, 2008a, 2009a, b), Carinthia (Bauer et al. 2007b) and Upper Austria (Jankowski et al. 2009).

From the seasonal variation of the PM₁₀ daily averages it became evident, that exceeding of the PM₁₀ air quality standard value of 50 µg/m³ took place generally during the cold season. Thus a first step included an analysis of different influences on the aerosol concentration during the warm and the cold season. Two possibilities had to be taken in consideration:

- During the cold season due to more frequent low level inversions ventilation is generally lower than during the warm season.
- During the cold season additional sources (e.g. domestic heating) are active compared to sources which are relatively constant throughout the year.

The influence of the ventilation was investigated by means of a traffic tracer, since traffic is a relatively constant aerosol emission source throughout the year. The main particulate exhaust emission from mobile sources is carbonaceous material. This, however, is also emitted from biomass and fossil fuel combustion. New tracer compounds from vehicular emissions are platinum elements used in the catalysts. Although emitted in very minor amounts, they can be used to investigate the ventilation issue. Limbeck et al. (2004) observed only a weak seasonal dependence of the Pd concentration in two cities explaining about 20% of the enhanced PM₁₀ levels in the cold season to originate from less ventilation (Klagenfurt and Salzburg).

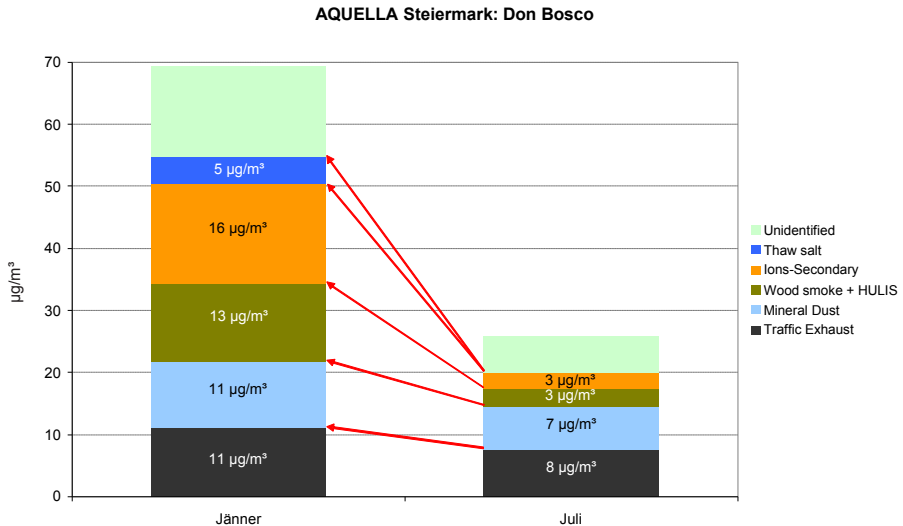


Figure 3: Comparison of source contributions for January and July 2004 at the urban site Don Bosco, Graz. From Bauer et al. (2007a).

The actual increase from a summer to a winter month was around 100-200%. As the macro-tracer results reveal, this increase is a result of specific "winter" sources. While Diesel-soot increases by the factor of wintry reduced ventilation (20-30%), the highest primary aerosol impact is from wood smoke and from thaw salt. A less discussed effect is the dramatic increase of ammonium nitrate, which is a result of the temperature dependent stability of the salt, with low formation tendency in the warm season, but stable conditions in cold and humid situations. Thus the cold season increase of ammonium nitrate is not an

emission dependent effect, it is a result of a shifted thermodynamic equilibrium. Figure 3 shows the comparison of the aerosol source contributions at the urban site "Don Bosco" in Graz for PM₁₀ for January and July.

For all urban sites studied, four main sources or source types responsible for the elevated PM₁₀ levels in the cold season were identified. The four main sources however show with quite variable contributions at the different sites and during the different exceeding periods:

- Street dust from grinded gravel and thaw salt used for streets under snow/ice conditions ("wintery street conditions"). Main emission take place during long lasting cold and dry periods, frequently occurring in the late winter.
- Ammonium sulfate and nitrate aerosol regional accumulation and transport from areas outside of the city area
- Smoke from wood combustion regional accumulation and transport from areas outside of the city area
- Diesel soot from traffic and off road sources

The AQUELLA experiments were planned as multiple site studies, thus, it was also possible to discriminate the rural concentrations – representing the background to the urban loadings. A surprising result of AQUELLA was that in many cases during pollution episodes a high background concentrations was present, which limited dramatically the additional "urban contribution" of an aerosol concentration which would keep the total PM₁₀ level (background plus "urban increment") below the limiting value. On the average during "exceeding days" (days exceeding the 50 µg/m³ threshold for PM₁₀ concentrations at the most exposed site) the background level contributed around two thirds, the urban increment one third to the PM levels measured at the exposed urban sites.

It became evident that in many of the exceeding periods the regional background levels were high due to two main aerosol sources:

- Wood smoke (including secondary material from wood smoke ("HULIS"))
- Ammonium nitrate and sulfate, particularly pronounced at the sites north and east of the Alps as a result of long range transport

The dominant impact of wood smoke and inorganic secondary material at AQUELLA background sites is evident from Figure 4.

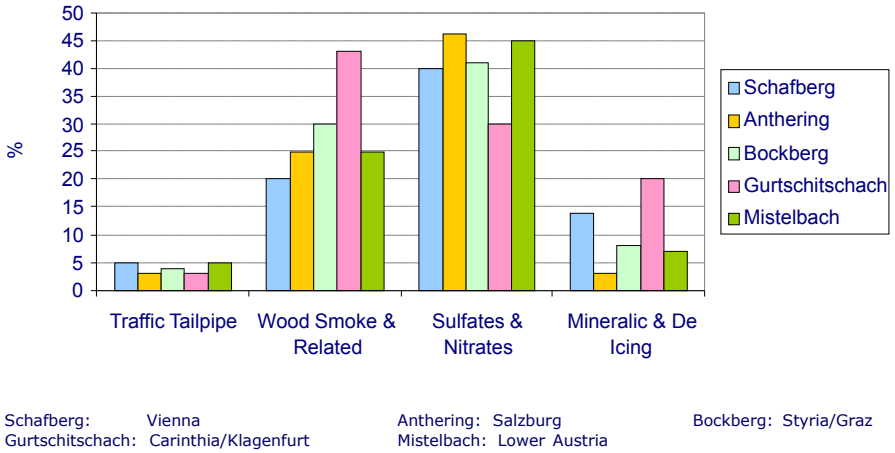


Figure 4: Source contributions at AQUELLA background sites in Vienna, Salzburg, Styria, Carinthia and Lower Austria during "exceeding periods" (Compiled from reports).

However, also at sites south of the main Alpine ridge the impact of secondary inorganic aerosol in the regional background is obvious. The overwhelming impact of the regional background (Lavamünd, Gurtschitschach) on PM₁₀ levels at the urban sites Koschatstrasse and Völkermarkterstrasse (in the city of Klagenfurt) is visualized for a three month period given as averages of "exceeding days" in Figure 5. The Klagenfurt basin is "filled" with a "lake" of wood smoke and inorganic secondary material, extending over a distance of more than 60 km. Within the city mainly mineral dust, carbonates, thaw salt and exhaust emissions increase.

Within a region considerable different types of episodes may occur. An example is given for Graz. In Figure 6 aerosol source contributions are shown for three different episodes, where in one case mineralic material, carbonates and thaw salt dominate the PM₁₀ composition; in the further case the aerosol is dominated by inorganic secondary aerosol (ammonium nitrates and sulfates; Episode from 25-28 Nov. 2004 is and a third case is dominated by wood smoke and traffic exhaust, indicating also a city source for wood smoke.

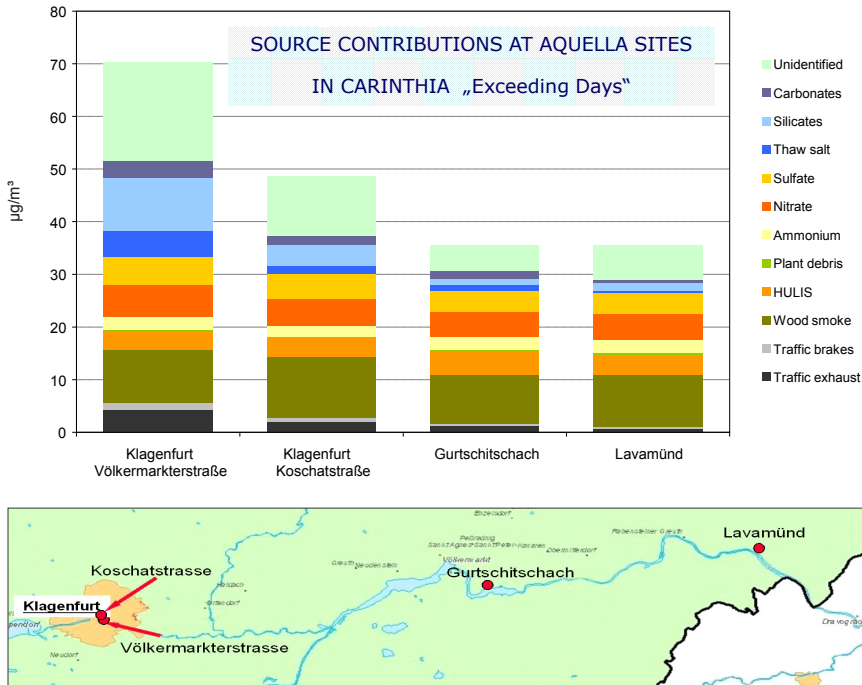


Figure 5: Source contributions at AQUELLA sites in Carinthia – averages for "exceeding days". (From Bauer et al. 2007b).

As a consequence from the AQUELLA results recommendations were derived for reducing PM₁₀ emissions:

- Reductions of the aerosol source strength of around 30-50% are required in a similar magnitude for the regional background as well as for the urban sites.
- For reducing the regional background reductions have to be considered for NO_x and ammonia in the air quality region, as well as reductions of NH₃, SO₂ and NO_x should proceed in European countries with respective high emissions.
- The use of log wood for combustion in "old" stoves should be restricted during PM₁₀ "alarm" situations, stove/boiler changes be considered. This applies to the countryside as well as to the urban districts.
- High mineral dust and thaw salt aerosol is a result of long lasting cold and dry winter periods. A task force for reducing this dust source is recommended to identify possibilities of less dustier wintry conditions.
- The reduction of exhaust PM and NO_x emissions as a consequence of the Euro5 and Euro6 emission regulations for new cars it is expected to miti-

gate the soot emission of cars and as well as of the NO_x emissions, which are currently an important precursor for the wintry ammonium nitrate aerosol.

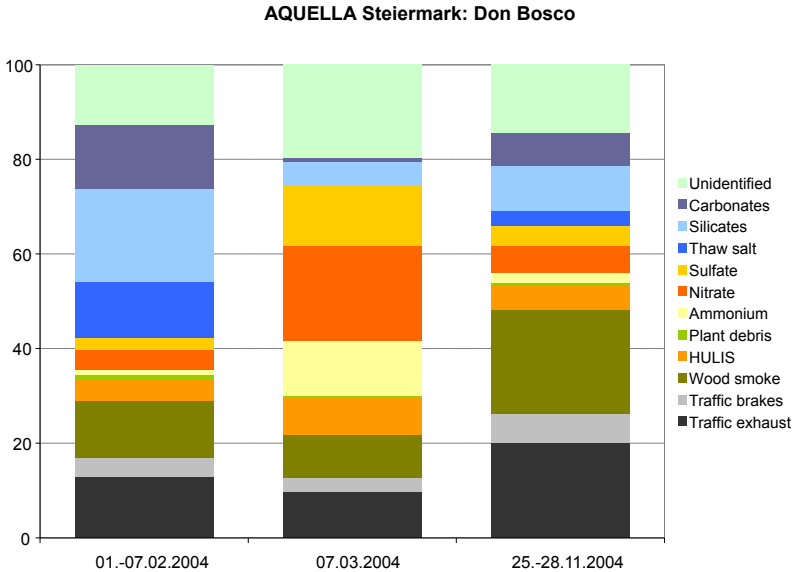


Figure 6: Different source signatures during three different PM₁₀ "episodes" in the greater area of Graz: Episode from 1-7 Feb. 2004 is dominated by mineralic material, carbonates and thaw salt; Episode from 7 March 2004 is dominated from inorganic secondary aerosol (ammonium nitrates and sulfates); Episode from 25-28 Nov. 2004 is dominated by wood smoke and traffic exhaust.

4. CARBOSOL (Aerosol chemistry and ice core aerosol trends)

The EU funded CARBOSOL project was a joint study of a network of international laboratories to investigate the present and retrospective state of organic versus inorganic aerosol over Europe. The coordinator was Michel Legrand of the LGGE (Laboratoire de Glaciologie et Géophysique de l'Environnement du CNRS, St Martin d'Hères, France).

"In this project we combine the study of spatial distribution and composition of the present-day carbonaceous aerosol in air and wet deposition in western/central Europe with the composition trends of climatically relevant carbonaceous material in Alpine ice cores spanning the last 150 years. The investigations include organic and inorganic constituents, EC/OC, WSOC and WinOC. Source apportionment (natural versus anthropogenic, primary emissions versus secondary production) is performed via selected organic tracers and ¹⁴C analyses. From Alpine ice cores we reconstruct past

atmospheric changes of relevant aerosol components over Europe by establishing air-snow relationships at the glacier sites. For some organic fractions this is the first report about the occurrence in early 20th century. Transport/chemistry models are used to investigate the net radiative effect of the change in aerosol load and composition (inorganic/organic) in Europe from the pre-industrial era to the present. Thus, the inversion of ice core aerosol signal is used in a regional chemical-transport model to estimate the underlying regional climate impact." (Legrand and Puxbaum 2007)

CARBOSOL ice-cores under investigation were from glacier fields at Monte Rosa and Mt. Blanc. The present day aerosol and precipitation was studied over a time span of two years at a set of 6 sites arranged over a west-east transect from the Azores (Atlantic Ocean) to K-Puszt (Hungary), including Azores (50 m elevation), Aveiro (50 m), Puy de Dome (1450 m), Schauinsland (1205 m), Sonnblick (3106 m) and K-Puszt. A regional circulation model coupled with a radiative transfer model in which aerosols are treated on-line was deployed to reconstruct the past evolution of aerosol emissions, concentrations and radiative forcing in Europe.

The present-day climatology of the aerosol gained during CARBOSOL was compiled by Pio et al. (2007). Carbonaceous aerosol concentrations showed a gradient of more than 20 times between the AZO marine background and the lowland continental sites of AVE and KPZ, with intermediate levels at continental mountain sites.

In a pioneering study source apportionment of the carbonaceous aerosol was achieved by combining measurements of organic macro tracers (levoglucosan for biomass combustion and arabitol for fungal spores, cellulose for plant debris) and a high sensitivity ^{14}C radiocarbon method for interpreting sources of EC and OC (Gelencser et al. 2007). Source types were lumped into primary emissions from fossil fuel combustion and biomass burning, plant-derived bio-aerosol, and secondary productions from precursors emitted by fossil and non-fossil sources. It has been found that while fossil-related sources predominate EC throughout the year at all sites, the sources of OC are mainly biogenic. In winter, biomass burning is the main OC source, with sizable additional contribution from fossil fuel combustion. In contrast, secondary organic aerosol from non-fossil sources becomes predominant in summer (Figure 7). From the levoglucosan data it is shown that biomass smoke is a very important constituent of the organic material in the mid and west European background in winter with contributions to organic matter of ~20% at the elevated mountain sites and 50-70% at polluted continental sites, not including secondary organic aerosol related to biomass combustion sources (Puxbaum et al. 2007).

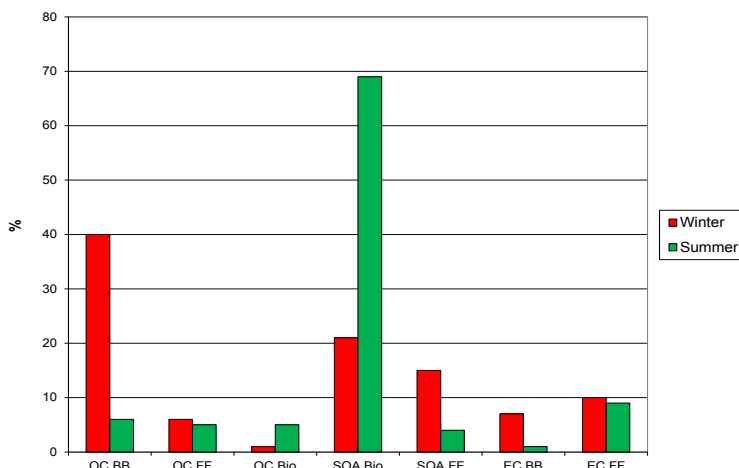


Figure 7: Source apportionment of EC, OC (primary) and SOA (secondary OC) at the site K-Pusztá (Background site in Hungary) during the winter and summer season. BB .. biomass burn, Bio .. biogenic particles, FF .. fossil fuel. Compiled from data in Gelencsér et al. (2007).

More than 200 compounds were identified and quantified by GC/MS, including alkanes, polyaromatic hydrocarbons, aldehydes, ketones, alcohols, sterols and organic acids in CARBOSOL aerosol samples. The organic compounds identified were used to evaluate the different sources with geochemical parameters and lipid source assignment. The GC/MS results confirmed the strong impact of biomass burning during winter at lowland sites (Oliveira et al. 2007). The weak amount of OC identified by such organic speciation (only 2-4% of the organic matter) stimulated the study of the oligomeric or polymeric matter. This was done for cellulose which, as expected, reveals higher concentrations in the growing season than in winter at continental surface sites. More surprising is the high relative concentrations of plant debris in organic matter observed at the elevated sites (5% in summer and 6-22% depending on elevation in winter) (Sánchez-Ochoa et al. 2007). Ubiquitous in organic aerosol, HULIS are a still ill-defined subset of organic aerosol mass and in fact no standard method is available for their determination. Using two different methods their climatology was investigated (Lukács et al. 2007, Feczko et al. 2007). Organic C2-C5 diacids were found to be significant contributors to "water soluble organic carbon" (from 3 to 7% at continental sites and up to 14% at Azores in summer) (Legrand et al. 2007a).

Carbonaceous species including filterable elemental and organic fractions, dissolved organic carbon, HULIS, and single organic compounds like carboxylic acids, levoglucosan, and cellulose were investigated together for the first time in high alpine snow deposits (Legrand et al. 2007b). An extended version of the EMEP 3-D chemistry-transport model was developed towards EC and OC and simulations were compared with observations in Europe. In additi-

on to primary emissions from fossil-fuel and wood burning, the model includes secondary production of anthropogenic and biogenic organic aerosol. The EMEP model reproduces well pollutants with well-know emissions and chemistry like sulfate but significantly under-predict EC, especially in winter (Simpson et al. 2007). For OC the performance of the EMEP model was evaluated not only with respect to observed OC but also for the first time against the levoglucosan analysis of Puxbaum et al. (2007) and the source apportionment calculations from Gelencsér et al. (2007). This powerful exercise indicates that underpredicted OC concentrations in winter (by a factor of 3 to 5) mainly results from an underestimated wood burning contribution in the model whereas in summer most of the departure (an underestimation by a factor of 2 to 3) is related to secondary production from both fossil-fuel and non-fossil fuel precursors not accounted for in the model.

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Human health effects

Manfred Neuberger

1. Introduction

The Austrian Clean Air Commission (Kommission für Reinhaltung der Luft, KRL) promotes the study of ambient air pollutants and their effects on human health, formulates air quality criteria and gives recommendations for standard setting. Originally this work was limited to outdoor pollutants, however, as today most time is spent indoors (home and workplace) from which other pollutants originate, for example tobacco smoke (Moshhammer et al. 2004), asbestos (Neuberger and Vutuc 2003, Moshhammer and Neuberger 2009a), non-fibrous particulates (Moshhammer and Neuberger 2004a), spores from moulds (Moshhammer et al. 2000) and many organic pollutants including toxins with long half-lives (Neuberger et al. 1999), the task of the KRL was enlarged. Gases and small particles from outside reach indoor spaces easily, but even larger particles such as pollen (Moshhammer et al. 2005) enter rooms and may interact with indoor pollutants from cooking and heating (Moshhammer et al. 2006). For some air pollutants the inhalation route is of minor importance only, because most of them reach the human body via the food chain and are stored in human tissues for decades (Neuberger et al. 2000).

2. Indoor pollution

Besides gases and fine particulates entering rooms from outside the indoor pollution most frequently found in Austria is tobacco smoke. In tobacco control Austria is still a developing country, where a quarter of non-smokers is still insufficiently protected from tobacco smoke at the work place (Klimont et al. 2007). In this nationwide survey 10% of non-smokers aged 15+ years reported to be exposed to tobacco smoke in the home, however, in another survey (European Commission 2007) 32% of Austrian smokers admitted to smoke regularly inside their homes in the company of non-smokers and another 47% irregularly. Except for Spain and Hungary the Austrian rate of smokers never smoking inside their homes in the company of non-smokers (21%) was exceeded in all other EU member states and reached 70% in Sweden. Nevertheless passive smoking in Austria is even more prevalent in public rooms, e.g. for eating and drinking outside the home (Pletz and Neuberger 2011). About half of adult non-smokers in Spain and Austria reported passive smoking during leisure time (Table 1). Meanwhile Spain realized the failure of a partial smoking ban, amended its tobacco legislation and thereby reduced tobacco smoke

exposure considerably (López et al. 2012), while the situation in Austria stayed unchanged (Neuberger and Moshhammer 2012).

Table 1: Percentage of passive smokers among 6545 non-smokers interviewed in 6 EU countries (Neuberger 2008a).

	E	A	SK	I	PL	IRL
home	28.7	18.1	11.0	13.3	22.1	11.5
work	35.2	19.2	25.0	34.2	40.2	1.3
leisure	56.1	47.8	37.0	7.8	21.5	8.5
transport	40.5	23.2	9.0	13.5	n.a.	6.2
TOTAL	71.9	66.2	41.0	36.8	35.9	23.4

These result of the survey shown in table 1 corresponds to high exposures in the tourism industry measured in Austria and Spain compared to other countries (Nebot et al. 2005, Gorini et al. 2008). Compared to EU average, Austrians are not smoking more frequently, but make less quit attempts (European Commission 2007) and have a high rate of relapse into smoking despite of using nicotine replacement (Neuberger 2008b) more frequently (European Commission 2007). This may be explained by a passive attitude expecting to be cured, disappointment from pharmacological treatment and lack of other help such as group therapy at the work place (Hutter et al. 2006, Moshhammer and Neuberger 2007). In addition, understanding for effects of passive smoking is poor in Austria (European Commission 2007), some politicians and media support tobacco industry and trade (Neuberger 2002) and disregard that both the World Bank and the World Health Organisation recommended high tobacco taxes (partly dedicated for tobacco prevention), smoke-free workplaces (without exemptions) and banning of all tobacco advertising as the most efficient methods to help the smoker to quit.

Among 29 European states Hungary, Spain and Austria reached the highest rate of smokers smoking at home in the presence of children (European Commission 2007). More than half of children in larger Austrian cities have to grow up in households with smokers (Neuberger et al. 2002, Moshhammer et al. 2006b). On average in the EU 9% of smokers did not care about children and 5% did not care about pregnant women when smoking in the car. In Austria this reckless behavior connected with extremely high air pollution was reported more frequently: 13% related to children and 8% related to pregnant women (European Commission 2007)¹. In a ranking of tobacco control in 30 European countries (based on taxation, legislation and funding) Austria got

¹ On average there are indications of improvements from the survey in Eurobarometer 2007 (European Commission 2007) to Eurobarometer 2010 (http://ec.europa.eu/health/tobacco/docs/ebs332_en.pdf), but not so in Austria (<http://www.aerzteinitiative.at/Eurobaro10.htm>).

the poorest score (Joossens and Raw 2006). The KRL expressed its concern that the non-smokers protection in the Austrian tobacco law does not reflect the state of science (Maurer et al. 2008) and informed the public that indoor air pollution from tobacco smoke threatens the health of children (Moshhammer et al. 2007) and the health of adults, too: The high exposures measured in Austrian restaurants put patients with asthma or heart disease at risk for an attack already during the short time of a meal and are capable to induce a myocardial infarction in patients with coronary heart disease (Neuberger 2008c).

Groups at high risk without protection are the unborn and the children (Moshhammer et al. 2007). Austria participated in a multi-center study of children aged 6 to 12 years, which had been designed to investigate respiratory health effects from ambient air pollutants, but found most pronounced effects from parental smoking (Pattenden et al. 2006). Maternal smoking during pregnancy had long-lasting effects on wheeze, asthma, and nocturnal cough, independent of postnatal exposure. On the other hand postnatal exposure to maternal or paternal tobacco smoke was associated with bronchitis, wheeze and nocturnal cough (independently of smoking during pregnancy). In a sub-sample of 22 712 children respiratory functions were measured in eight regions in Europe and North America, including 2 825 elementary school children in Austria. Lung function growth was found impaired from passive smoking (Moshhammer et al. 2006a). Even if passive smoking was limited to the months before birth, respiratory functions of the children were impaired for many years. Children whose mothers smoked during pregnancy were 31% to 40% more likely to have poor lung function in elementary school. Postnatal exposure independently increased risk of poor lung function by 24% to 27% and independently from the effects of prenatal exposure.

In children from households with gas cooking vital capacity and forced expiratory volume in one second were reduced by 2% (Moshhammer et al. 2006). This reduction was attributed to the exposure to nitrogen dioxide (NO_2) and corresponded to even more pronounced impairments of respiratory functions associated with outdoor NO_2 from motor traffic and diesel engines in particular (Moshhammer et al. 2006b).

3. Outdoor pollution

Based on several severe air pollution episodes, a temporal correlation between high concentrations of particulate matter (PM), sulphur dioxide (SO_2) and acute increases in respiratory and cardiopulmonary mortality had been established in Vienna for the 1970's (Neuberger and Moshhammer 2004). Afterwards air pollution decreased in Austria, as documented by data on SO_2 , and total suspended particles (TSP). During the 1980's Austria achieved the highest SO_2 reduction among the signatory states of the Helsinki Protocol,

however, other sources of fine particulate matter like diesel traffic increased. Also other traffic related pollutants like NO₂ remained a problem, in particular in cities with high density of population and cars. Therefore, short term effects of PM on lung function, morbidity and mortality were investigated in Vienna, Linz, Graz and a rural control area (Hauck et al. 2004, Neuberger et al. 2002, Neuberger et al. 2004). Long-term exposure and chronic disease – even more important for public health – were studied in repeated cross-sectional, a mixed longitudinal and a birth cohort study on school children in the city of Linz (Neuberger et al. 2002). After having established reference values of lung functions for Austrian children (Neuberger et al. 1999) their development was studied from entering elementary school to adulthood: Lung function growth was found impaired from long-term exposure to air pollutants and improved in districts where ambient air pollution had decreased. Where only TSP and SO₂ had decreased, no continuous improvement of small airway function was found and end-expiratory flow rates stayed impaired where NO₂-reduction from technical improvements of cars and industry was counterbalanced by increase of motorized (in particular diesel) traffic (Neuberger et al. 2002). In contrast to the study on effects of indoor NO₂ from gas stoves (Moshhammer et al. 2006), however, these effects of outdoor NO₂ may have been partly caused by ultrafine particles from diesel engines and other components of traffic pollution accompanying NO₂.

Active surface of particles inhaled several hours to days before spirometry was found related to short-term reductions in forced vital capacity, forced expiratory volume in one second and maximal expiratory flow rate at 50% of vital capacity. In pupils with asthma or previous airway obstruction 4-week-diaries proved that the following symptoms increased with daily exposure to urban particles characterized by their active surface area: wheezing, dyspnea, cough when going to sleep and cough at night (Neuberger et al. 2004, Moshhammer and Neuberger 2003). A rise in fine mode concentrations (PM_{2.5}) of 10 µg/m³ was linked to an increase in hospitalization of preschool girls by 8%, of school girls by 6%. A rise in carbonaceous fine particles (e.g. as caused by diesel-powered vehicles) in Vienna was also associated with adverse respiratory effects in kindergarten children (Horak et al. 2002). In adults effects were found on respiratory admission rates especially for the elderly. In persons older than 65 years bronchitis/asthma increased by 5.5% in men, and by 5.6% in women (Neuberger et al. 2004). First response of the respiratory system to a rise in fine particles seems to be a discrete, sub-clinical lung function impairment in children followed by symptoms of adverse effects in susceptible subpopulations and increased hospital admissions of elderly persons: Few hours after an increase of active particle surface in ambient air we recorded a slight increase in respiratory resistance and a slight decrease in peak flow (Moshhammer and Neuberger 2003). In the city of Vienna a significant increase in hospital admissions for bronchitis/asthma was found 2–4 days after a rise

in PM_{2.5}: in elderly men and school girls after 2 days, in elderly women after 3 days, and in pre-schoolgirls after 4 days (Neuberger et al. 2004). A second significant peak in hospitalizations was observed in elderly persons 10 days after a rise in fine dust concentration. Besides these significant changes respiratory admissions stayed (insignificantly) elevated from the day of exposure to the end of the observation period of 14 days. Similar observations were made in Lower Austria (Neuberger et al. 2004).

The reaction of the cardiovascular system to fine particulates is even quicker and affects larger numbers of elderly persons (Neuberger 2007, 2008c). In the cities of Graz and Linz the increases of hospital admissions for cardiovascular disease per 10 $\mu\text{g}/\text{m}^3$ were highest for PM₁ followed by PM_{2.5}, PM₁₀ and NO₂. No significant effects were found for O₃, not even during summer. Effect modification was seen by temperature, humidity, particle number, SO₂ and H₂S. In Linz where a steel plant contributes to PM exposure, significant effects were found in both sexes on the same day for PM and NO₂ and again after 2 days for NO₂ and after 6 days for PM. In Graz where local motor traffic dominates PM pollution, effects on admissions were found significant on the same day for NO₂ and after 6 days for PM. Admissions of females increased more per 10 $\mu\text{g}/\text{m}^3$ of PM than admissions of males. Even levels of air pollution below the current EU standards were associated with cardiovascular admissions (Neuberger et al. 2008).

Recent mortality studies in the three largest Austrian cities considered cumulative and latent effects up to two weeks by use of time series with polynomially distributed lags (Neuberger et al. 2007a–c). Figure 1 shows that daily mortality in Vienna in 2000–2004 increased by 0.8% per 10 $\mu\text{g}/\text{m}^3$ of NO₂ on the same and the following day, by 2.1% during the first week and by 2.9% over a period of two weeks (Neuberger et al. 2007c). This indicates that deaths accumulate during 14 days after an increase of air pollutants because of latent effects, while harvesting (reduced mortality after short increase due to premature deaths of most sensitive persons) is of minor importance for the net effect. A similar increase is seen in Figure 1 for fine particulates; however, PM₁₀ had only been monitored for 3 years and PM_{2.5} for 4 years, so that it had to be modeled for part of the observation period from TSP and meteorology.

In Graz a similar study was conducted from 1995 to 2005, evaluating daily pollution monitored at 5 stations, meteorology and incidences of influenza as registered by sentinels (Neuberger et al. 2007b). Like in Vienna effects of epidemic influenza exceeded air pollution effects on total and cardiopulmonary mortality, however, they were higher than the means reported from multicenter European studies (Ballester et al. 2008). This was attributed to the longer latency periods analysed, the high proportion of diesel vehicles in the car fleet and the aged population in these two cities. In Graz total mortality increased per 10 $\mu\text{g}/\text{m}^3$ of NO₂ by 1.2, 2.0 and 2.6% if cumulating effects up to 1, 7 and 14

days. For PM₁₀ the corresponding increases were 1.3, 1.5 and 1.6%. The high mortality change with NO₂ indicates the importance of motor traffic, which also is the main source of fine and ultrafine particulates in Graz, followed by wood combustion. Somewhat lower increases of mortality per µg of pollutant (NO₂, PM_{2.5}, PM₁₀) per m³ of air were found in Linz. Nevertheless mortality increases were significant and accompanied by increases of cardiopulmonary emergency transports (Neuberger et al., submitted).

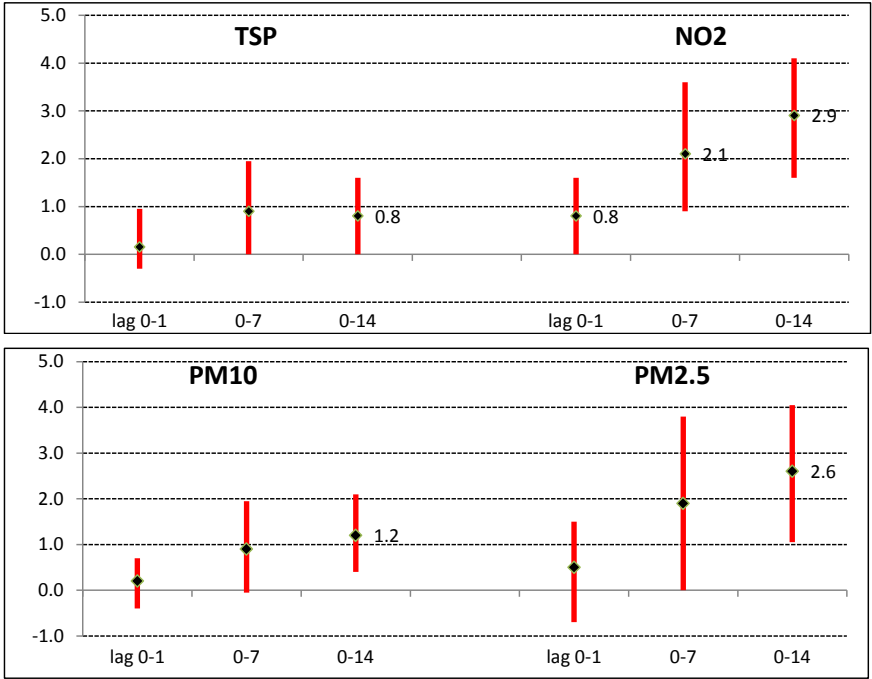


Figure 1: Total mortality increase in Vienna – percent per 10 additional µg/m³ of the respective air pollutant (daily air pollution).

Besides NO₂ no other gaseous copollutants monitored influenced daily mortality. SO₂ was too low to be of importance and for ozone no effects on mortality could be proven if heat and humidity were taken into account. Neither for the total periods analyzed in Graz, Linz and in Vienna nor for the summer months a significant effect of daily ozone on mortality was detected. However, this could be related to the monitoring strategy for ozone, which is measured mainly at elevated or downwind locations with lower population densities.

Per µg of fine particulates or NO₂ even higher increases of mortality were observed in cohort studies, which capture effects with latencies much longer than 2 weeks. Little is known on the mechanisms of irreversible long-term effects of PM such as myocardial infarction and cancer. In a prospective cohort study on 1630 dust-exposed and 1630 non dust-exposed male workers mat-

ched for age and smoking (Neuberger 1979) the exposure (nonfibrous, insoluble particulate matter in metal, ceramics, glass, stone industry) was related to cancer incidence (Neuberger et al. 1988). In dust exposed workers significant increases of deaths from lung cancer, stomach cancer, chronic obstructive and restrictive lung disease (underlying or main causes of death) were found. Lung cancer was significantly increased also in dust exposed workers without silicosis (Moshhammer and Neuberger 2004b).

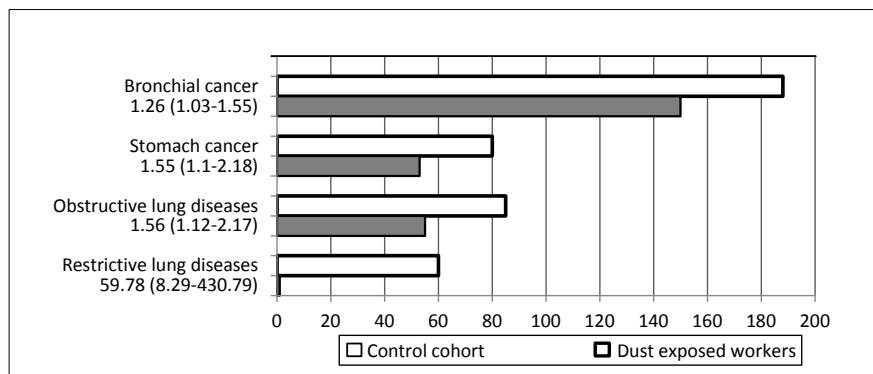


Figure 2: Deaths from bronchial cancer, gastric cancer and chronic lung disease in dust exposed and non dust exposed workers matched for smoking.

Other studies were able to relate lung cancer to specific particles like those from diesel engines, and a large prospective study (Pope et al. 2002) linked lung cancer in the general population with long-term exposure to PM_{2.5}, mainly from combustion processes. All these epidemiological findings should have consequences for occupational and ambient air standards. Both NO₂ and fine particulates need to be reduced in ambient air. Health benefits of reducing NO₂ have been shown (Neuberger et al. 2002). From an earlier literature survey the Austrian Clean Air Commission decided already to recommend a lowering of the standard for the maximal daily mean of NO₂ to 80 µg/m³ (Tvrđy et al. 1998).

The present standard for PM_{2.5} in the European Union will not prevent acute and chronic health effects sufficiently (Neuberger et al. 2007c). Reducing annual mean levels of PM_{2.5} to 15 µg/m³ could lead to a reduction in the total burden of mortality among people aged 30 years and over that would be four times greater than the reduction in mortality that could be achieved by reducing PM_{2.5} levels to 25 µg/m³ (1.6% vs 0.4% reduction). The percentage reduction could grow by more than seven times if PM_{2.5} levels were reduced to 10 µg/m³ (3.0% vs 0.4%), equivalent to the standard recommended by the World Health Organization (Ballester et al. 2008).

4. Outlook

Recently new hazards were identified from nanoparticles (Neuberger and Moshhammer 2010) indoors and outdoors. At work places in Austria the most frequent source of hazardous particles in the submicron range (around 100 nm) is environmental tobacco smoke (Neuberger 2009). Active and passive smoking is associated with 61% of male cancer mortality in Austria (Borsoi et al. 2010) and overall with about eleven thousand premature deaths annually (about 10 000 from active smoking and 1 000 from second hand smoke), mainly from cardiovascular causes (Maurer et al. 2011). Possibly effects of passive smoking have been underestimated (Pock et al. 2010), because of the non-linearity of the dose-response curve (Smith and Peel 2010) and the higher prevalence of second hand smoking in Austria compared to other countries (Wallner et al. 2010).

Other indoor sources of air pollution such as gas cooking have been found to be associated with only minor reductions in lung function of children (Moshhammer et al. 2010). In the future, however, furnaces could gain importance again as a source of indoor and outdoor pollution and related health risks (Haluza et al. 2012). From the replacement of all oil fired furnaces in Upper Austria without stricter particle emission standards for wood fired furnaces as recommended by the Clean Air Commission (Popp et al. 2007), 48 excess deaths are expected in the first year, increasing later to approximately 174 excess deaths per year (Moshhammer and Neuberger 2009b).

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In vitro research work

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1. Background

The present review highlights the most relevant in vitro-research work dealing with fine particulate and air pollutants done in Austria during the last decade. As the public and scientific awareness of health impairment due to ambient pollutants is rising, several national scientific groups specialized on diverse topics concerning air pollutants with main focus on the effects of cigarette smoke components. Obviously, both scientific know-how and technical equipment in this research field are available in this country to be competitive at an international level, as several publications show that are described below. In order to ensure a high level of research quality, only papers published in a peer-reviewed journal and listed in the PubMed database were taken into consideration.

In general, the definition of in vitro and in vivo-research refers to the applied experimental model. Therefore, in vitro-research is the manipulation of tissues, cells or biomolecules in a controlled, artificial environment, serving as an approximate reconstruction of a living plant, animal or human being (in vivo). The great benefits of this method are the possibility to modify single variables of any biological process and analyze the effects of modifications in a highly standardized, rather inexpensive, and feasible way.

2. Cigarette smoke components

Cadmium

Environmental pollutants are a very delicate public health issue with adverse health effects, ranging from asthma to increased mortality rates. As a fact, airborne particles containing organic and inorganic substances in low doses activate the immunological chain reaction by influencing the chemokine production of immunocompetent cells and further relevant cell types such as epithelium and endothelium (Chauhan et al. 2005). For example, the trace element cadmium (Cd) found in cigarette smoke shows acute and chronic health effects including immune system alterations. Messner and colleagues showed with in vitro-experiments that Cd is a promoter of atherosclerotic lesions by increasing endothelial cell permeability and inhibition of cell proliferation (Messner et al. 2009). Considering this immunological background, Marth et al. performed an elegant in vitro-study to assess the interaction of pollutants with the gene expression of various cytokines that are important for cell

communication and immunomodulation (Marth et al. 2000). Peripheral blood mononuclear cells were exposed to cadmium chloride (CdCl_2). Afterwards, the keyplayer-cytokines beta-actin, ICAM-1, IL-1alpha, IL-6, IL-4, TNF-alpha, IL-4 and IFN-gamma as well as the heat shock protein HSP70 were quantified. Especially HSP70 is a suitable marker for cell reaction to pathophysiological and environmental stress (Ciocca et al. 1993). As a result, CdCl_2 was able to stimulate these components of the human immune system at low concentrations, whereas a higher dose had an immunosuppressing effect. Based on this work, the authors showed that low doses of cadmium were also able to inhibit the production of the immunoglobulin IgE by stimulated human B cells, but enhanced the amount of secreted IgE and did not alter IgM release (Jelovcan et al. 2003). In conclusion, these observations were able to give an explanation for the inflammatory and mucous swelling effects of pollutants such as heavy metals in the airways.

Standardized cigarette smoke extract

Cigarette smoking is known to have various detrimental health effects, including allergic airways symptoms. To investigate the pathophysiological mechanisms of the development of allergic disease, Gangl et al. incubated cultured human bronchial epithelial cells with ingredients of cigarette smoke in order to mimic the in vivo-situation of exposure with active and passive smoking (Gangl et al. 2009). Interestingly, in this setting, the treatment with smoke extract weakened the epithelial cells, leading to a more than threefold increase of cell permeability for some of the major respiratory allergens (Bet v1, Phl p5, Der p2) and a subsequent stimulation of histamine production in histamine release experiments. These results indicate that the substances found in cigarette smoke reduce the barrier function of the respiratory epithelium for allergens and, thus, may cause or exacerbate allergic inflammation.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are abundantly found in cigarette smoke and diesel exhaust. In a recent publication, the possible immunotoxic effects of PAHs were evaluated with a screening assay using transfected human cell lines and subsequent measurement of luciferase activity (Oostingh et al. 2008). For this screening method, Oostingh et al. used a panel of chemokines and cytokines that were administered to cultured T cells (Jurkat) and lung epithelial cells (A549). Both cell types are crucial in immune defense. The PAH fluoranthene was applied to establish the assay. This substance has been found to contribute to the increasing incidence of allergic diseases in humans and rodents (Kanoh et al. 1996, Polosa et al. 2002). Furthermore, the in vitro-effects of the wide-spread PAHs phenanthrene, pyrene, and anthracene were

evaluated. As a pro-inflammatory standardized factor, recombinant human TNF-alpha was used to simulate a rather initial immune process resulting in a vast chemokine production. The authors stressed that their newly developed assay would be a useful system for the screening of various substances in a cheap, simple, and easy manner. What is more, it could serve as an alternative for animal testing of any ambient toxins.

3. Allergens

A Viennese research group concentrated on the role of allergen-specific T cell-priming in cord blood from women that were exposed to both inhalant and nutritive allergens during gestation. In a first attempt, a placenta model was used consisting of in vitro-perfused placentas from uncomplicated term pregnancies to directly examine transplacental transfer of two chosen substances, the milk allergen beta-lactoglobulin and the birch pollen major allergen Bet v1 (Szepfalusi et al. 2000, Schneider et al. 1972, Reisenberger et al. 1996, Fortunato et al. 1992). These allergens were able to cross the maternofetal barriers and could be detected in the fetal circulation. Furthermore, cord blood mononuclear cells were incubated with birch pollen allergen and timothy grass allergen (Szepfalusi et al. 2000). Simultaneously, maternal blood samples were treated equally to rule out the influence of maternal exposition to inhalable allergens. The data suggest that these allergens have a positive effect of fetal lymphoproliferative activity at gestational age of 20 weeks, supporting the idea of a modulatory function of the placental barrier concerning the T cell-response to allergen contact.

4. Halogenated substances

The aryl hydrocarbon receptor (AhR) is a ligand-activated nuclear transcription factor that mediates responses to halogenated aromatic toxins such as the so-called xenodioxin 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), polynuclear aromatic hydrocarbons, combustion products, and numerous chemoprotective phytochemicals such as flavonoids. TCDD induces tumors in animals and in humans, whereas natural AhR ligands tend to protect cancer. Both TCDD and phytochemicals inhibit estrogen-induced breast and endometrial neoplasms, suggesting that the AhR can provide an important target for development of therapeutic drugs for treating these cancers (Safe 2001). Schaufler et al. investigated the effects of TCDD in vitro on hormone-resistant prostate cancer cell lines (Schaufler et al. 2002). As the expression of the phase 1 and 2 metabolism genes of the cytochrome P450 superfamily CYP1A1 and CYP1A2 are regulated by AhR, they were used as unspecific markers for AhR activation (Hu et al. 2007). It was shown that cell growth was not altered, whereas CYP1A1 and CYP1B1 were significantly induced in high passage num-

bers, pointing towards a potential role of an environmental toxin in causing a less effective drug therapy in advanced states of prostate cancer due to CYP induction.

5. Conclusion and outlook

Research on environmental and air pollutants is of high importance considering that air quality is a key environmental concern for quality of life and public health. Besides monitoring networks and data collection of air pollution, in vitro-research is essentially needed to fully understand how the various ambient air pollutants behave and affect the environment and life forms on a molecular level. Interdisciplinary cooperation and communication should be strengthened in the future to ensure a broader scientific as well as public discussion of important findings of in vitro research work on pollutants in Austria.

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Integrated assessment modelling

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1. Introduction

To provide policy-relevant information on effective control strategies for reducing negative impacts of aerosols on human health and climate change, integrated assessment models are being developed. Such models bring together scientific information on the individual aspects of atmospheric PM (i.e. emissions, atmospheric transport and transformation, health impacts) into a single scheme, so that responses of the overall system to changes of individual elements can be explored. Integrated models allow identifying strategies at the local, regional and global levels that protect the atmosphere while imposing the least burden on economic development. In Austria, integrated models covering aerosols have been created by the International Institute for Applied Systems Analysis (IIASA).

IIASA develops innovative modelling tools that enable search for sets of emission control measures that simultaneously meet environmental targets on air quality and greenhouse gas reductions at least costs. Of particular importance are emissions of aerosol precursors (e.g. SO₂, NO_x, NH₃, VOC, PM_{2.5}), which deteriorate air quality at the local scale and cause negative impacts on human health, agricultural crops, natural vegetation and man-made material. At the same time, these emissions influence near-term climate change, as they exert radiative forcing at the regional scale. The analysis takes full account of the interactions between different control measures and pollutants, and thus allows highlighting synergies and trade-offs of particular strategies.

Strategies designed by IIASA are being used as a foundation for short- to long-term policy development by decision makers in the developed and developing worlds.

2. IIASA's approach

IIASA's interdisciplinary research develops a systems perspective that encompasses a variety of aspects that are relevant for environmentally and economically effective pollution control strategies. Its GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model addresses threats to human health posed by fine particulates and ground-level ozone, risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated levels of ozone, as well as radiative forcing. These impacts are considered in a multi-pollutant context, quantifying the contributions of

sulfur dioxide (SO₂), nitrogen oxides (NO_x), ammonia (NH₃), non-methane volatile organic compounds (VOC), and primary emissions of fine (PM_{2.5}) and coarse (PM_{2.5}-PM₁₀) particles. GAINS also accounts for emissions of the six greenhouse gases that are included in the Kyoto protocol, i.e., carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and the three F-gases (Table 1).

Table 1: The multi-pollutant/multi-effect approach of the GAINS model (open circles indicate linkages that are not yet considered in GAINS).

	PM	SO ₂	NO _x	VOC	NH ₃	CO ₂	CH ₄	N ₂ O	HFCs PFCs SF ₆
Health impacts									
- ambient particulate matter	•	•	•	•	•				
- ground-level ozone			•	•				□	
Vegetation and eco-systems damage									
- ground-level ozone			•	•				□	
- acidification		•	•		•				
- eutrophication			•		•				
Climate impacts									
- Long-term radiative forcing at the global scale	•	•	•	•	•	•	•	•	•
- Instantaneous radiative forcing at the regional scale	•	•	•	•	•				

GAINS holds the essential information on all aspects listed above for 43 European countries and links this data in such a way that the environmental implications of alternative assumptions on economic development and emission control strategies can be assessed. On-line access to the model and to all input data is available at <http://gains.iiasa.ac.at>. The GAINS model allows simulation of the costs and environmental impacts of user-defined emission control scenarios. Its optimization mode balances emission control measures across countries, pollutants and economic sectors in such a way that user-defined target levels on the various environmental impacts are met at least costs.

To describe these interactions, the GAINS model brings together scientific knowledge and quality-controlled data on future socio-economic driving

forces of emissions, on the technical and economic features of the available emission control options, on the chemical transformation and dispersion of pollutants in the atmosphere, and the resulting impacts on human health and the environment. The GAINS model combines information on:

- economic development that determines current and future levels of anthropogenic activities
- historic statistics and future projections on the levels of emission generating activities (e.g., energy use, industrial production, agricultural activities, etc.)
- emission characteristics of the various activities
- measures that are available to reduce emissions from all sources
- the costs of such measures
- the chemical conversion and transport of emissions in the atmosphere
- the impacts of pollution to human health, vegetation and ecosystems
- the impacts of these pollutants on radiative forcing in the near- and long-term

With such a systems perspective, GAINS enables a holistic assessment of the costs and environmental benefits of alternative emission control strategies. In particular, its optimization approach facilitates the design of portfolios of measures (to be taken in different sectors, for different pollutants and in different regions) that achieve user-defined air quality and climate objectives at least cost.

Such a systems perspective is particularly relevant for acting on both fronts against climate change and local air pollution. As many measures to reduce one type of pollution have (positive or negative) impacts on the other, there exist considerable co-benefits as well as potential trade-offs. For example, measures that aim to reduce fossil fuel combustion in order to reduce greenhouse gas emissions will have ancillary benefits for regional air pollutants; improving structural measures in agriculture can reduce both regional air pollution and climate change; the abatement of CH₄, which is both an ozone precursor and a greenhouse gas, has synergistic effects, and some cheap abatement measures may be highly cost-effective. In contrast, enhanced use of diesel cars would reduce CO₂ emissions, while it would exacerbate health effects from fine particulate matter unless efficient particle filters are applied.

IIASA's analysis provides a comprehensive framework to systematically address such interactions, and to search for strategies that maximize synergies for multiple benefits. Results find interest in international science and are adopted for policy processes.

3. Interactions between air quality and climate change

Analysis with GAINS demonstrates that cost-effective strategies, which selectively allocate specific reduction measures across economic sectors, pollutants and regions, could achieve the air quality improvements of a conventional across-the-board approach at only 50% of the costs. In developing countries, measures to eliminate indoor pollution from the combustion of solid fuels will form an integral element of such an air pollution control strategy. However, well-designed air pollution control strategies can also reduce emissions of greenhouse gases. For achieving given targets on ambient air quality, the cost of air pollution can be further reduced by adopting certain low carbon measures, such as energy efficiency improvements, fuel substitution, co-generation of heat and power, integrated coal gasification combined cycle (IGCC) plants. For instance, a model study for India and China (Rafaj et al. 2009) demonstrates that such measures would reduce air pollution at lower costs than a conventional approach that relies on technical end-of-pipe emission control measures. At the same time greenhouse gas emissions would be lower (see Figure 1).

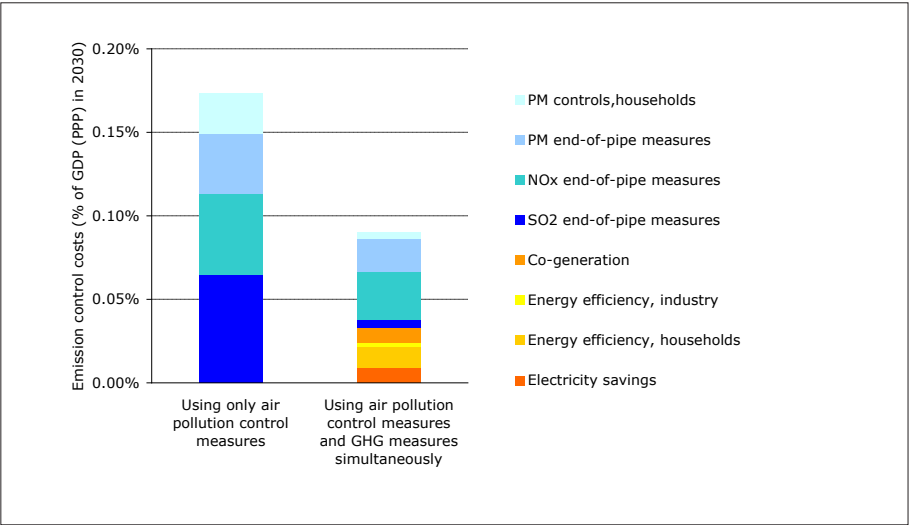


Figure 1: Emission control costs for reducing PM health impacts in China by 50% in 2030.

The GAINS model presents clear evidence that co-control of CO₂ and air pollutants leads to significant co-benefits of greenhouse gas mitigation on non-climate policy objectives, inter alia for the protection of human health, ecosystems and agricultural production. Such co-benefits occur both in industrialized and developing countries, and they emerge in the near term and close to the locations where mitigation measures are taken. Thus, a comprehensive

assessment of the costs and benefits of greenhouse gas mitigation must not ignore such co-benefits (Shindell et al. 2008).

Some of the emission reductions that occur as a co-control of CO₂ mitigation (e.g. of SO₂ emissions) lead to additional warming in the near term, as presence of such short-lived substances exert in the atmosphere exert a cooling effect upon formation of light reflecting particles. Thus, such co-controls of cooling agents will compensate some of the climate benefits from CO₂ mitigation in the next few decades. At the same time, optical active particles (black carbon, BC) which absorb light will contribute to warming and counter the effect of the reflecting particles. The direction and extent of such combined effects is matter of intense scientific debate and will strongly depend on the respective conditions (Penner et al. 2010, Borken-Kleefeld et al. 2010). Thus improving the database on BC emissions is a high priority (Lamarque et al. 2010, Koch et al. 2010, Bond et al. 2004). Also, the uncertainty in the causal chain between anthropogenic activities and climate change deserves to be scrutinized (Prather et al. 2009).

4. Application in science and policy

IIASA's analysis has been applied for key international environmental agreements in Europe to inform negotiators about cost-effective sets of emission reductions that achieve environmental policy targets at least cost. Under the Convention on Long-range Transboundary Air Pollution, the RAINS model, i.e., the predecessor of the GAINS model focusing on air quality only, was used to identify emission ceilings for the negotiations of the Second Sulfur Protocol in 1994 and the Gothenburg multi-pollutant/multi-effect Protocol in 1999, and the revision of the Gothenburg Protocol in 2012. For the European Union, the GAINS model developed the quantitative proposals for the Directive on National Emission Ceilings in 1999, and provided the scientific backbone of the 'Clean Air For Europe' programme that prepared the knowledge base for the EU Thematic Strategy on Air Pollution in 2005. Currently, GAINS is used to inform European negotiators for the revised Emission Ceilings Directive of the EU (Amann et al. 2010, Cofala et al. 2009). In the up-run for the Copenhagen Climate Summit, IIASA developed estimates of mitigation potentials and costs of greenhouse gas emission reductions for the Annex I countries (Amann et al. 2008, Amann et al. 2009).

A decisive element to apply an integrated assessment model in policy is the ability to relate the environmental pressures (emissions) and the abatement scenarios to the respective policy targets. In Figure 2, the loss of statistical life expectancy is the target value displayed against modelled concentrations of anthropogenic PM_{2.5}.

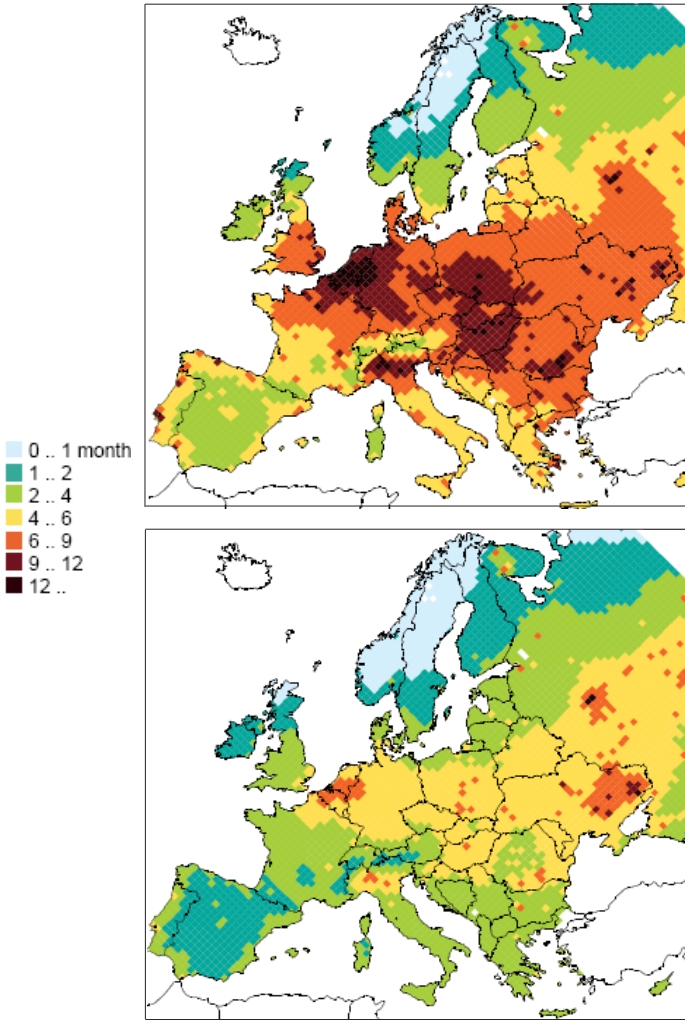


Figure 2: GAINS estimates of loss in statistical life expectancy attributable to exposure to PM_{2.5} from anthropogenic sources (in months). Upper panel: 2000; lower panel: baseline projection for 2020. These estimates have been used in the Clean Air For Europe (CAFE) program of the European Commission to establish the air quality targets of the EU Thematic Strategy on Air Pollution.

Recently, IIASA also contributed to the 'Assessment of Black Carbon and Tropospheric Ozone' of the United Nations Environment Program (UNEP 2011; Shindell et al. 2012) and explored the scope for control of short-lived substances that could complement efforts to reduce long-lived greenhouse gases and thereby minimize the negative climate impacts of SO₂ controls.

Based on the GAINS model, IIASA identified 16 measures that reduce emissions of CH_4 and black carbon so that the global radiative forcing from these substances could be cut by two thirds in the near term. These measures, all of which are already successfully applied in practice in different parts of the world, are complementary to CO_2 mitigation measures. They include measures to control emissions of CH_4 from coal mines, production and distribution of oil and gas, from waste management and livestock farming, as well as measures directed at emissions of black carbon (e.g., particle filters for diesel engines, clean cooking stoves, agricultural waste burning, etc.). The analysis shows that rapid implementation of these measures throughout the world could reduce global temperature increase in the next few decades by up to 0.5 (0.3-0.7) degrees. Larger reductions would occur in Asia, where the main potential for further reductions of these substances exists, and in the Arctic. Most of these measures affect sources that are not in the focus of CO_2 mitigation, and would thus not be taken in the interest of climate change mitigation. However, together with CO_2 mitigation, these measures would substantially increase the chance to keep the global temperature increase below 2 degrees (see Figure 3).

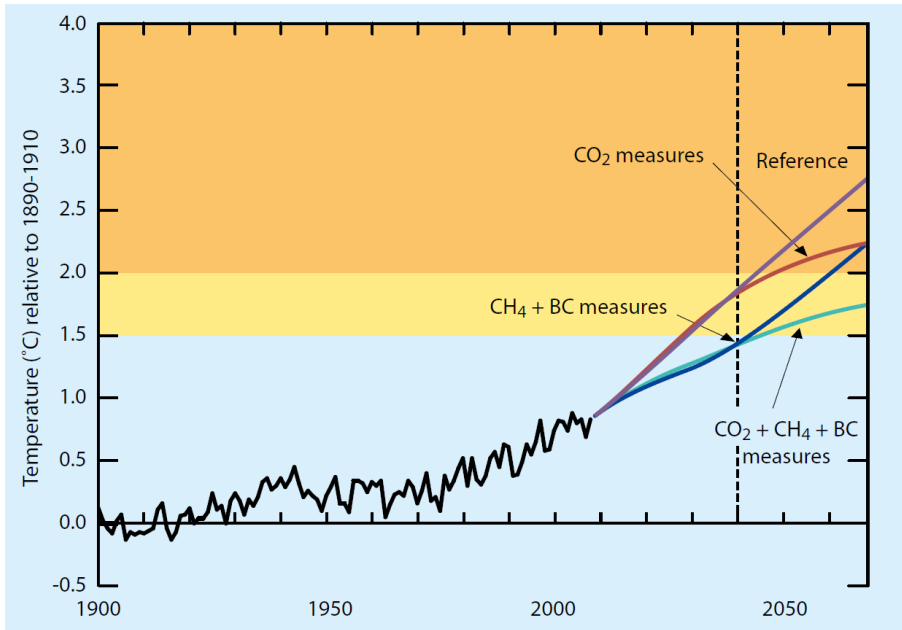


Figure 3. Observed deviation of temperature to 2009 and projections under various scenarios. Immediate implementation of the identified BC and CH_4 measures, together with measures to reduce CO_2 emissions, would greatly improve the chances of keeping Earth's temperature increase to less than 2°C relative to pre-industrial levels. The bulk of the benefits of CH_4 and BC measure are realized by 2040 (dashed vertical line).

In addition to their climate impacts, these measures have substantial benefits on human health and agricultural production as they also lead to improved air quality at the local scale. Since they affect air pollution emissions and impacts for which (inter-) national policy institutions are already in place, they could be implemented under existing local and regional air quality legislation regimes. Furthermore, many of these measures would contribute to existing development objectives (e.g., access to clean energy and water, waste management, introduction of more efficient energy production technologies, etc.).

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Austrian project on health effects of particulates¹

Helger Hauck

1. Overview

AUPHEP is a research project carried out by the Clean Air Commission of the Austrian Academy of Sciences in cooperation with the following institutions: Institute of Experimental Physics of the University of Vienna, Institute of Environmental Health and University Children's Hospital of the Medical University of Vienna, Institute for Chemical Technology and Analytics of the Vienna University of Technology, Institute for Meteorology of the University of Natural Resources and Applied Life Sciences, Vienna, Pulmonary Center of the city of Vienna, Office for Youth and Family Affairs of the City of Linz, Federal Environment Agency, Vienna, Air Quality Departments of the Federal Austrian States, City of Vienna – MA-22 (chemical laboratory). The project was started in 1998 and was completed in 2004 (Hauck et al. 2004a).

The project was funded by the Federal Ministry for Science and Traffic, the Federal Ministry of Environment, Youth and Family Affairs, and the Austrian Academy of Sciences. Additional financial support came from the Ambient Air Monitoring Networks of the Federal Austrian States, the Federal Environment Agency, as well as several companies.

In the middle of the last century high concentrations of particulate air pollution (PM – particulate matter) were a serious menace to human health (e.g. London smog episodes). Extensive technical and regulatory measures taken in the industrialized countries led to a considerable reduction of PM concentration. Nevertheless, epidemiological studies (e.g. "Six Cities Studies" in the USA) demonstrated that even at relatively low PM concentrations (varying around air quality standards) there is a positive statistical association between PM concentrations and adverse health effects. Especially the fine fractions with diameters smaller than 2.5 µm proved critical; they affect the respiratory tract and the cardio-vascular system particularly in susceptible groups such as children, the elderly, and individuals with pre-existing diseases. Although intense research was carried out in this field during the last 25 years, the causal links between PM burden and adverse health effects could not be determined unambiguously. The latest research findings provide convincing evidence that even at very low PM concentrations there is a relationship between health effects (increased mortality and more frequent disorders of the respiratory tract

1 Reprint from AUPHEP-Endbericht, Kommission für Reinhaltung der Luft, Österreichische Akademie der Wissenschaften, Wien 2004 (http://www.oeaw.ac.at/krl/publikation/documents/AUPHEP_EB.pdf).

and the circulation system) and PM-burdens. The causal agent (mass concentration, number concentration, surface, composition etc.) could not be identified with certainty to date.

2. Monitoring programs

The purpose of the Austrian project was to give an overview on the ambient air quality situation with special emphasis on PM; the monitoring sites were selected in an effort to reflect the typical Austrian situation. The interaction of the different PM-parameters and the characteristic chemical composition of the aerosol with respect to the current meteorological situation could thus be evaluated. At four sampling sites where SO₂, NO/NO₂, TSP, and O₃ and the most important meteorological parameters were already being monitored, continuous measurements were carried out for TSP (total suspended particles) PM₁₀, PM_{2.5}, PM_{1.0}, and particle number concentration. Implementation of various measurement techniques allowed investigation of the equivalence of these results also with respect to aerosol composition (Hauck et al 2004b).

The 12 months monitoring series demonstrate only a weak variability between summer and winter in the mass concentrations of all fractions in Vienna and Streithofen (NÖ), the sites in Linz and Graz – having higher concentrations in general – indicate a clear maximum in winter. At all urban sites the particle number concentrations are higher, peaking in winter; the rural site at Tullnerfeld has nearly equal concentrations in both seasons. Trajectory analyses revealed that these sites are well suited in most (but not all) cases to serve as background stations for Vienna (Gomišček et al. 2004a). In general, higher PM concentrations above the current standards are more common in winter due to the unfavorable weather conditions (e.g. low mixing layer: Gomišček et al. 2004b).

The PM₁₀- and PM_{2.5}- fractions were also collected as diurnal sample by means of a high volume sampler and underwent thorough chemical analysis. The analytical measurement program included ions, trace metals, soot, and organic carbon. The chemical analysis revealed the influence of aerosol sources. Due to the parallel sampling at the urban station in Vienna (AKH) and the background station at Streithofen it was possible to detect metropolitan influences in the aerosol formation processes. The metropolitan contribution to the PM₁₀ concentration at the AKH site showed an annual mean of 22% (Puxbaum et al. 2004). During monitoring campaigns (in summer and winter) using specially designed high resolution impactors soluble ions and a number of heavy metals within different size-modes could be identified (Berner et al. 2004).

3. Health effects studies

The data derived from these monitoring series are the basis for the subsequent studies on health effects of particulates. They are compiled in a database and are collected on a CD-ROM, thus made available.

The effects of particulate air pollution on the lung function of children were investigated in an epidemiological survey conducted with two cohorts (PM effects on the lung function of one- and two-year old children, PM effects on the lung function of elementary school children: Horak et al. 2000, Neuberger et al. 2002, Moshhammer et al. 2006). In another study, time-series analyses were carried out using health data from Vienna, Tullnerfeld, Linz, and Graz including exposure data collected in these areas. Morbidity data (hospital discharges with relevant diagnosis recorded around the monitoring stations) and mortality data due to respiratory and cardiovascular diseases were linked with the exposure and weather data (Neuberger et al. 2005).

The relationship between the two causal pollutants SO_2 and suspended particles on the one side and premature deaths due to bronchitis/asthma on the other observed in previous time-series studies in Vienna, could no longer be found in the years 1999–2001, a benefit from improved air quality (emission control in industry and domestic heating). A rise in fine mode concentrations ($\text{PM}_{2.5}$) of $10 \mu\text{m}/\text{m}^3$ is commonly linked to an increase in hospitalization of persons older than 65 years for bronchitis/asthma, i.e. 5.5% in men, and 5.6% in women. But not only the elderly are affected, hospitalization of children goes up too, of preschool girls by 8%, of school girls by 6%. A rise in carbonaceous fine particles (e.g. as caused by diesel-powered vehicles) in Vienna was associated with adverse respiratory effects in kindergarten children. First responses to a rise in fine particles burden are characterized by discrete, sub-clinical lung function disorders in children followed by symptoms of adverse effects in susceptible subpopulations living near the monitoring site and increased hospital admissions with attributable diagnosis in the whole metropolitan area. Some hours after an increase in active surface recorded at a monitoring station in Linz, an examination of children of a nearby primary school revealed a slight increase in respiratory resistance and a slight decrease in peak flow (Moshhammer and Neuberger 2003). In the city of Vienna, however, a significant increase in hospital admissions for bronchitis/asthma triggered by a rise in $\text{PM}_{2.5}$ occurred two or more days after the event: in men over 65 years after 2 days, in women over 65 years after 3 days, in schoolgirls after 2 days, in pre-schoolgirls after 4 days (see this compendium, pp. 103 ff). A second peak in hospitalizations was observed in persons over 65 years 10 days after a rise in fine dust concentration. One day after the event, a significant increase in specific mortality due to ischemic heart disease (myocardial infarction) in persons older than 65 years – independent of temperature – could be observed. Lung disorders occurred after an increase in $\text{PM}_{2.5}$ and PM_{10} , but an increase in

ischemic heart disorders could only be found after a rise in fine particle concentration (PM_{1.0}, PM_{2.5}, PM_{2.5}-PM_{1.0}). Due to the short latency interval it must be supposed that premature deaths due to heart disease are a direct consequence of the penetration of fine particles into the blood via the lung, impairing the coagulation mechanism and interacting directly with the heart.

In a longitudinal PM exposure study carried out with schoolchildren in Vienna, Tullnerfeld, and Linz a total of 2 913 children of the second and third grade from seven schools in Vienna and Tullnerfeld respectively and from 10 schools in Linz was examined. The children's parents filled out a questionnaire four times (one per season), the children were directly interviewed. Current and previous respiratory disorders along with allergic responses and chronic diseases of the child and his family, the life style of the child, and demographic features were recorded. The main points of the examination were the overall evaluation of the respiratory health as judged by the parents together with an asthma score derived from the present symptoms and the medication. The influence of the PM burden was analyzed using a mixed regression model, with the time-activity parameters being the PM fraction and the climate data of the last four weeks preceding the personal interviews. The age of the child at the beginning of the inquiry, gender, allergies of the child and his family, asthma of the family, passive smoking, truck traffic in the residential area, general traffic density in the residential area, domestic cooking or heating with gas and the presence of moulds in the home were included as fixed variables.

Associations with the asthma score proved weak or non-existent. The variability of medium-term PM burden is generally not linked with the variability of asthma symptoms. In Tullnerfeld however, the findings showed a systematic correlation between the PM_{1.0} fraction, to a certain extent also the PM_{2.5} fraction, and the severity of the symptoms. A clear relationship was found between the fine dust concentration during the reference period and the overall evaluation of the lung condition. High PM_{2.5} concentrations were linked with an aggravated risk for impending lung injuries. The analysis strongly suggested that this increase was due to the PM fraction ranging from 1.0 to 2.5 μm . The two impactor campaigns carried out in summer and winter clearly demonstrate that the mass concentration in this area varies with the fine and coarse fraction and is therefore an indicator of the physical aerosol processes which play an active role in the accumulation and fractioning of particles. Since truck frequency in the residential area of the children is an important factor of the incidence of respiratory disorders, diesel soot seems to be one of the causal agents of occurrence and severity of the symptoms.

In summary, compared to former years, these time-series studies indicate an improvement in air quality but still give evidence of a prevailing high fine dust concentration. This is a serious hint that further research is urgently needed

for the protection of human health in general and of susceptible subpopulations in particular.

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Outlook

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1. General

Atmospheric aerosols are important for many atmospheric processes. The liquid or solid particles provide surfaces for condensation as well as for chemical reactions of gaseous and non-gaseous atmospheric constituents. Inside a bulk particle the considerably higher density enables conversion processes at much higher concentration (and conversion rates) than in the gas phase, and moreover facilitates the transport of trace material over large distances. Particles affect the optical properties of the atmosphere. They form nuclei for particle growth and cloud droplet or ice particle formation and contribute to the self-cleansing mechanisms of the atmosphere through wet and dry deposition. While being present as trace constituents only, the high surface-to-volume ratio of airborne particles enhances the effects particles may have on substrates, specifically on human body tissues and impacting human health.

The contributions collected in this compendium demonstrate the wide variety of topics that need to be covered in order to respond to the challenges posed by the presence of fine particles in the atmosphere. While focusing on research performed in Austria, the issues of the current state of scientific discussions are reflected in general.

2. New directions

Challenges for research typically arise from societal needs as much as from the scientific progress itself. Some of the open questions in aerosol research have been addressed in the previous sections of this report.

European legislation requires member countries to comply with PM₁₀ air quality standards (max. 35 exceedances – 25 according to the somewhat stricter legislation in Austria – of 50 µg/m³ as a daily mean value, and an annual mean of 40 µg/m³) in order to safeguard the health of the European population. Ambient monitoring needs to be provided by administrative bodies, and in the case of exceedance action plans need to be established. This routine exercise would not require scientific support. Scientific questions to be addressed, however, are rather posed by the allowed exemptions, i.e. quantifying the contributions of natural sources. Exceedances due to contributions from such sources, according to EU legislation¹, may be subtracted when assessing compliance if they can be determined with sufficient certainty.

1 Directive 2008/50/EC of the European Parliament and of the Council.

This requires, on the one hand, consistent and precise methods to determine the contribution of natural aerosols (e.g. Saharan dust, sea salt), which cannot be controlled in principle. On the other hand, the protection of citizens requires to study in more detail to which extent such aerosols remain health relevant, as health effects may warrant additional efforts in reducing anthropogenic pollution. Soluble particles potentially may carry less risk, as they are immediately being resorbed in the human body unless they contain an insoluble core.

Improvements of metrics with regard to health relevant parameters will constitute a future challenge in general. PM_{2.5} has been recognized already as being more relevant to health than PM₁₀, and thus is also subject to limits. The EU set a standard of 25 µg/m³ as an annual mean (valid from 2015), which does not fully address proven health risks (Ballester et al. 2008) and is lacking a short term limit (Neuberger et al. 2007). Possible other metrics, which have not seen sufficient scientific confirmation yet, are the particle number and surface, the insoluble fraction of aerosols, (certain) organic compounds, aerosol acidity, and heavy metals.

The development of nanotechnology and the engineering of nanoparticles have been discussed as a potential future threat. Long multiwalled carbon nanotubes showed similar changes in animal experiments as naturally occurring asbestos fibers (Poland et al. 2008, Takagi et al. 2008), indicating additional risk due to uptake of engineered nanoparticles. While being of considerable concern for indoor environments and an issue of workplace safety, an extrapolation to all nanomaterials and the environment in general does not seem to be justified. In ambient conditions, considerable dilution of such new engineered nanoaerosols will occur and thus concentrations likely far too small to become relevant compared to existing ultrafine particles, such as fresh combustion aerosol.

Future attempts to understand the effects of PM pollution on human health will need to, more strongly, consider individual exposure. It will be of interest to understand why, under the conditions of often strikingly different concentrations indoors compared to outdoors, outdoor air influence still is discernable even if people spend only a fraction of their time outdoors.

Another scientific challenge will derive from changing exposure patterns over time, e.g. regarding cigarette smoke. While reducing exposure to passive smoke in offices, public buildings and restaurants improves health conditions, it will become more difficult to assess the influence of effects related to outdoor air, combined effects of pollutants from outdoor and indoor sources and compare studies performed at different times. Positive developments in the indoor environment may thus add to the number of confounders to be separated in epidemiological studies, adding to the need for more detailed exposure assessment.

The ever-increasing anthropogenic impact on natural cycles (Haberl et al. 2007) also poses challenges in terms of aerosols. Aerosols may be carriers of toxic substances, pathogens, or of radioactive material. With the appropriation of natural processes by humans in the era of the anthropocene (Steffen et al. 2007), not only the scientific interest of understanding natural processes needs to be satisfied, but also the cause-effect relationships of certain human activities require clarification. Furthermore geo-engineering impacts as well as side-effects need to be isolated at a level of sufficient confidence.

The importance of aerosols on the global radiation budget has been recognized already in the previous IPCC assessment reports. A major drawback in properly assessing the topic also with regard to international agreements, in order to reconcile short-term and long-term climate targets, consists of the limited scientific knowledge to translate emission abatement into measures of climate protection. Quantifying the aerosol effects and reducing the huge uncertainties associated will be urgently needed.

3. The role of science in Austria

Society's challenges as outlined above can and will be the subject of future scientific efforts. With the demand directed to human health on the one hand, and climate related studies on the other hand, the need for monitoring sites also extends towards urban as well as background stations (the latter also covering situations of health relevant background aerosol). While routine monitoring is not a task of science, KRL in a vision paper focuses on measuring sites in the city of Vienna itself, and on the Sonnblick observatory at an elevation of 3105 m a.s.l – the former predominantly with respect to human health impacts, the latter to assess background conditions including the global background considered relevant for climate related questions. Both sites are well established to also support instrumental development.

Further functions, effects and uses of aerosol may come up in the future. Tasks can hardly be predicted in detail but may be derived from events in the past. Examples include high altitude aerosol from a volcanic eruption with possible effects on air traffic safety, as measured on Sonnblick observatory during the Eyjafjallajökull eruption in 2010, or even questions about extraterrestrial prebiotic or life signs, with aerosols as carriers and particles being transported across extremely life-adverse environments. Based on the successful previous collaboration of the respective institutions and researchers, Austrian science will be able to participate in as well as lead international atmospheric aerosol research.

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Glossary of Terms

Aerosol	Solid or liquid phase material (fine particulate matter) dispersed in a gas phase
BC	Black Carbon; usually used for analyte of optical methods
BLPI	Berner Low Pressure Impactor
BrC	Brown Carbon; thermally refractory and weakly light absorbing component in biomass smoke
CAVI	Cascade Virtual Impaction Surface Impactor
CCN	Cloud Condensation Nuclei
DMA	Differential Mobility Analyzer
DWOPS	Dual Wavelength Optical Particle Spectrometer
EC	Elemental Carbon; usually used for analyte of thermal methods
OC	Organic Carbon, thermally volatile carbonaceous material
OPC	Optical Particle Counter
PDMA	Parallel Differential Mobility Analyzer
PM	Particulate matter
PM10	Particulate matter smaller than 10 μm (aerodynamic) diameter
PM2.5	Particulate matter smaller than 2.5 μm (aerodynamic) diameter
SMPS	Scanning Mobility Particle Spectrometer
TSP	Total suspended particles

About the Authors

Markus Amann leads the 'Mitigation of Air Pollutants and Greenhouse Gases' program at the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. At IIASA he coordinated the development of the RAINS and GAINS models for air pollutants and greenhouse gases and their policy applications. Inter alia, he served as lead author to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, the Report on Ozone of the UK Royal Society, and the UNEP Black Carbon Assessment. Dr. Amann graduated in Electrical Engineering at the University of Technology, Vienna, Austria and received his PhD in Economics from the University of Karlsruhe, Germany.



Gerhard Bachler is scientist at the Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology. Since his employment at the Department for Traffic and Environment he worked on research projects dealing with the PM10 burden on local and regional scale (micro- and mesoscale). Next to detailed emission inventories for certain regions in Austria his activities focused on the analysis of air quality measurement campaigns close to paved and unpaved roads to detect the amount of traffic on total PM10 burden. Furthermore the effects of alternative winter service (de-icing and sanding) with CMA (Calcium-Magnesium-Acetate) are of interest to reduce traffic induced PM10 non exhaust burden.



Axel Berner, Professor at the former Institute for Experimental Physics, University of Vienna, retired in 2000. Instrumentation for characterising fine aerosol particles was his main research field. Aerosol centrifuges of high resolution, low pressure cascade impactors for nano particles, and later on HiVol cloud water collectors are the highlights of his work. He participated in many international projects on characterisation of atmospheric aerosols in Europe. He is still interested in properties of time series of aerosol data, especially time dependent correlation of atmospheric aerosol concentrations and, more recently, characteristics of their fluctuations.



Daniela Haluza works as a medical doctor and university lecturer at the Institute of Environmental Health, Center for Public Health, at the Medical University Vienna. Her current research focus is in health communication and preventive medicine. Awarded with a science scholarship, she wrote a thesis about the patho-anatomical specialities of the human lymphatic system at the Clinical Institute of Pathology at the General Hospital Vienna. For this research work, Daniela Haluza employed various bioanalytical techniques including in-vitro cultivation of endothelial cells and lymphocytes.



Regina Hitzemberger is Professor for Aerosol and Cluster Physics at the Faculty of Physics of the University of Vienna. Her main fields of research are atmospheric aerosols, their physical properties and role in cloud formation and carbonaceous particles in the atmosphere (focus on soot particles). During the past several years, she studied cloud condensation nuclei and their properties in depth and developed an optical measurement method to differentiate between Diesel soot (black carbon) and biomass smoke (brown carbon) in atmospheric aerosols. Dr. Hitzemberger has a Doctorate of Philosophy in Physics and was awarded the title "Universitätsdozent" in experimental physics by the University of Vienna.



Wilhelm Höflinger is employed at the Institute of Chemical Engineering of the Vienna University of Technology since 1979. Since 1994 he is the head of the department "Mechanical Process Engineering" within the above mentioned institute. From 2000 till 2002 he was the head of the Institute and since 2002 he is the head of the research area "Mechanical process Engineering and air pollution control techniques". 2009 he gained the title of a University Professor. He is member of various scientific working groups and has organised several international scientific conferences. Since 2008 he is Chairman of the International Delegation of Filtration (INDEFI) and chairman of the 11th World Filtration Congress. He has about 250 papers in the field of Mechanical process engineering.



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Helger Hauck is a retired Professor for Environmental Hygiene at the Medical University of Vienna. During his academic carrier he was also Professor for Medical Physics. He is vice chairman and long term member of the Clean Air Commission of the Austrian Academy of Sciences and thus involved in most of the work of this group. As Chairman of the Clean Air Commission of the Austrian Standards Institute he was involved in national and European environmental standardization work.



Christian Kurz works as senior researcher at the Institute for Internal Combustion Engines and Thermodynamics at the Graz University of Technology. Within the framework of his doctoral thesis a combined emission-dispersion tool for air quality inventories was developed and tested for the city of Klagenfurt. This methodology has already been applied to most major cities in Austria. During the last years he published an approach to calculate the NO-NO₂-formation dependent on the primary NO₂ emissions and developed the algorithm for the "VBA Umwelt Steiermark" (flexible speed limits dependent on air quality). Before his employment he studied process plant engineering at the Graz University of Technology.



Manfred Neuberger is a medical doctor since 1971. He was deputy director of Vienna Municipal Institute of Environmental Medicine 1989-99. Since 1999, Dr. Neuberger is full professor at the Medical University of Vienna. He is consultant of WHO (IARC, IPCS, ECEH), UNDP, ILO, EC (DG research) and board member of societies of toxicology, pneumology, hygiene, occupational and environmental medicine. Moreover he is member of the European Network for Smoking and Tobacco Prevention (ENSP) and web-master of the related website www.aerzteinitiative.at. He published 450 papers and books, mainly on health effects of air pollution, cancer epidemiology and lung disease.



Hans Puxbaum became Professor of Analytical Chemistry at the Institute for Analytical Chemistry, Technical University Vienna in 1991. He established the research of Atmospheric Chemistry at TU Vienna. The group was involved in the investigation of acidic gases and particles in the atmosphere, elemental carbon (soot), ultrafine particles, organic acids, atmospheric polymeric compounds (cellulose, "Humic-like-substances") and of atmospheric bioparticles. He participated in a number of EUROTRAC-Projects and EU-Projects and organised the aerosol source study "AQUELLA" in 7 Austrian counties. He is now Academic Director of the "Environmental Technology and International Affairs" (ETIA) program at TU Vienna.



Peter J. Sturm is professor at Graz University of Technology, Austria. His current position is head of the section "traffic and environment" at the Institute for Internal Combustion Engines and Thermodynamics. The focus of the research work is in the field of urban air quality. A further major activity is in the field of tunnel ventilation and safety, with a focus on road tunnels. Peter Sturm is member of the "Austrian Clean Air Commission of the Austrian Academy of Sciences, in the Committee on Transport and Air Pollution" of the Transport Research Board (USA), several working groups in the Austrian Research Association for Road, Rail and Traffic and represents Austria in PIARC (world road association) technical committees for safety, ventilation and operation of road tunnels.



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