Comparing lung deposition of ultrafine particles caused by fireworks and traffic

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Abstract

Every year New Years celebrations are carried out across the world by individuals as well as official organizations involving fireworks, creating concern about an estimated intense particle load in densely populated areas (Barman et a., 2008). Therefore, this campaign investigated the size distribution of aerosols in the range below 1 µm, comparing its influence on lung deposition. As an interesting side observation, it was also possible to document a period of temperature-inversion. Sampling sites were located in the downtown area of Salzburg, Austria, measuring New Years fireworks particle load and comparing it with background aerosols as well as traffic exhaust during a typical work day under winter weather conditions.

Introduction

Most environmental monitoring campaigns rely on measuring PM_1, $PM_{2.5}$ or PM_{10}. This does not reflect the actual impact on human health, as depositions vary widely depending on the particle size distribution and the amount of ultrafine particles. Although PM_{10} is somewhat correlated with trends in ultrafine particles, it did not provide enough evidence that physical ultrafine particle properties can be proportionally downscaled from PM_{10} (Rosenbohm *et al*., 2005).

During this measurement campaign we were also confronted with characteristic meteorological conditions favoring stationary temperature inversion at ground level (see Fig. 1). Hence , an interesting constellation, enabling not only short-term determination of particle inventory due to firework-generated aerosols, but also a long-term exposure due to prolonged inversion conditions, along with locally generated traffic aerosols from crucial transit roads radiating out from the urban area into the adjacent country side contributed to their shares in the pool of gathered data.

Methods

Environmental aerosol concentrations were sampled with an SMPS system (Grimm 5400 series) consisting of a long-sized DMA connected to a CPC, covering a sampling window between 11.1 and 1038 nm grouped in 44 size-channels.

To investigate the fate of inhaled particles, we applied the stochastic lung model developed by Koblinger & Hofmann and Hofmann & Koblinger (both 1990) to model deposition over the above mentioned size range using the 44 output channels of the SMPS. Data pairs of number concentration and geometric mean diameter per size class were used to run the stochastic model. In this model the geometry of the airways along the path of an inhaled particle is selected randomly using a Monte Carlo code IDEAL, whereas deposition probabilities are computed by deterministic formulae. This model enables computation of total, regional and differential particle deposition in a stochastic lung structure.

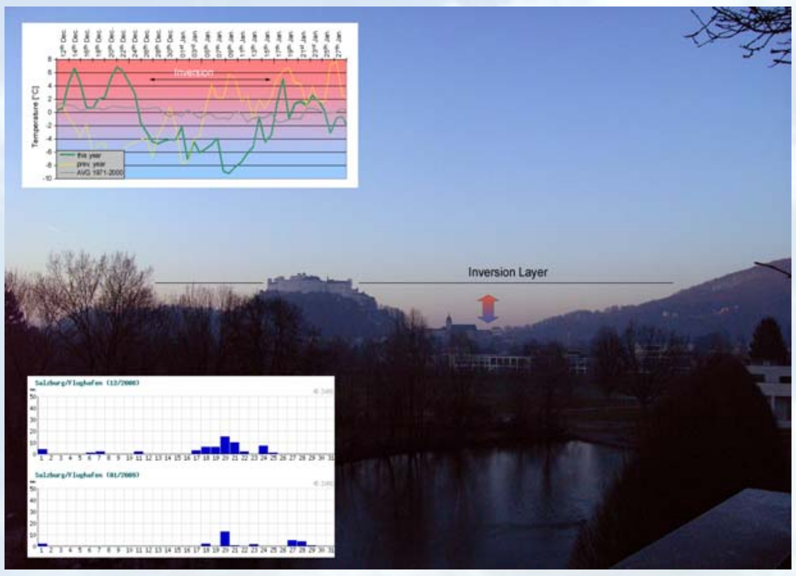

Fig. 1: Stationary temperature inversion at ground level during the sampling campaign in the Salzburg basin. Inlets: Mesoclimatic characteristics during the sampling campaign.

Results

The sampled nano-particle inventories show great differences in their size distributions (Fig.2). Both fireworks and traffic aerosols reveal similar total particle concentrations of 78,790 N/cm³ (fireworks) and 75,518 N/cm³ (traffic) respectively, within the detection window from 11 to 1100 nm. Due to the observed low temperatures however, traffic related aerosols created significantly more particles below the 100 nm range, while the aerosol fingerprint originating from firecrackers peaked past the 100 nm threshold – a difference that is of great influence for the deposition in the human lungs. Both kinds of aerosols are relevant for acute or short-term exposure. The more homogenously distributed background aerosols resulting from the accumulation during the inversion setting with an average concentration of 40274 N/cm³ reflected a bimodal pattern in which aerosol populations at around 20 nm and 100 nm dominated. Since this distribution is relevant for long-term or chronic exposure it has profound significance for individuals suffering from respiratory complications. Figure 2 reveals also the background aerosol concentration in absence of stationary temperature inversions of a normal winter-workday with a total average particle concentration around 8274 N/cm³ - a value still twice / 3-times as high compared to those observed during the warmer months of the year.

In order to investigate the fate of the sampled particle size-distributions the data have been applied for the stochastic lung deposition model developed by Koblinger & Hofmann (1990), which shows distinct lung depositions past the 15th generation. Figure 3 displays a distinct higher particle deposition from traffic- and firework- related aerosols in the alveolar region. While exposure to these bursts of elevated aerosol concentrations are usually limited in time (in the case of vehicle exhaust either by being stuck in traffic, or as a bystander watching firecracker activity), aerosol exposure during a stationary temperature inversion event is definitely more of a problem. Since the occurrence of a stationary temperature inversion events - in our case it lasted almost four weeks (see upper inlet of fig.1) - are a peculiar phenomenon confined to the cooler months of the year. In topographical settings where such conditions occur frequently throughout the year, this definitely represents a serious challenge to local authorities.

In combination with periodic diurnal fluctuations of traffic aerosols (related to the morning and evening rush hours) such avers meteorological conditions leading to ever increasing aerosol concentrations in urban centers can create a situation in which individuals with existing respiratory difficulties may experience aggravated and acute cardio-pulmonary symptoms as well as increased risk of chronic symptoms, including even premature death (Devra et al., 2002). Already Donaldson et al. (1988) pointed out that particle deposition in the alveolar region can only via by the immune system, as this is the primary organ to remove entrapped particles.

Indeed, fatalities can indeed be related to air pollution has been shown by Hunt et al., (2003). Table 1 lists the confirmed cases that have been related to the catastrophic aerosol exposure episode in London in December 1952, where some 4,000 excess deaths occurred at the height of the event, with some 12,000 fatalities attributed to the aftermath of the 1952 smog (Hunt et al., 2003). Although concentrations of air-borne pollutants drastically exceeded current EPA-standards (ACE 2002), the table illustrates the link between aerosols and human health in a wider urban setting.

Case	DoD	Age [yr]	Sex	Diagnosis 1	Diagnosis 2
1	03-Dec	65	M	Pulmonary embolism	Lung cancer
2	06-Dec	53	M	Heart failure	Bronchitis
3	07-Dec	76	F	Heart failure	Bronchitis
4	10-Dec	20 hr	M	Prematurity	
5	12-Dec	54	F	Emphysema	Hodgkin's disease
6	17-Dec	51	F	Sarcoidosis	
7	19-Dec	53	M	Heart failure	Bronchitis
8	25-Dec	51	M	Pneumonia	Tubercular meningitis*
9	04-Jan	60	M	Heart failure	Syphilitic aortitis
10	16-Jan	62	F	Heart failure	Emphysema
11	12-Jan	6 months	F	Pneumonia	Possibly cystic fibrosis
12	14-Jan	55	M	Bronchitis*	Gastric ulcer
13	17-Jan	64	F	Esophageal cancer	Aspiration
14	23-Jan	61	M	Bronchitis*	Emphysema
15	23-Jan	44	F	Bronchitis*	Pneumonia
16	28-Jan	62	F	Lung abscess	
17	12-Feb	61	M	Heart failure	Bronchitis
18	05-Mar	66	M	Emphysema*	Myocardial infarction

Table 1. Confirmed deaths of the London smog with analysis of autopsy tissue, by demographics and cause of death (***** autopsy note: condition worsened during smog).

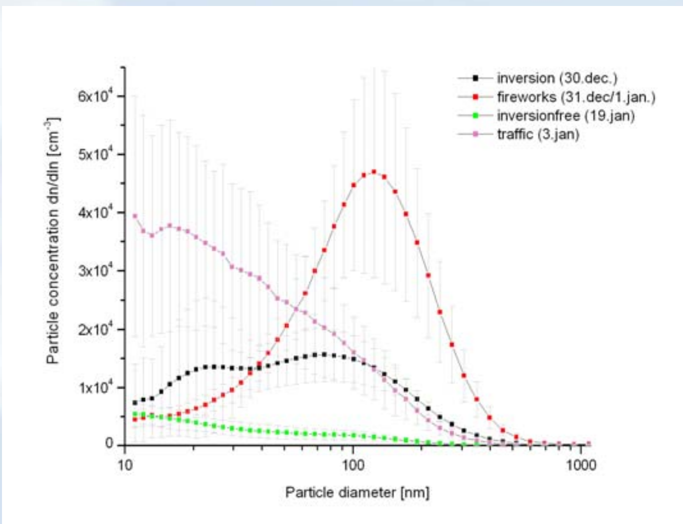

Figure 2: Particle size distribution averages comparing fireworks, traffic exhaust, and a prolonged event of temperature inversion compared to a normal winter\s day background value.

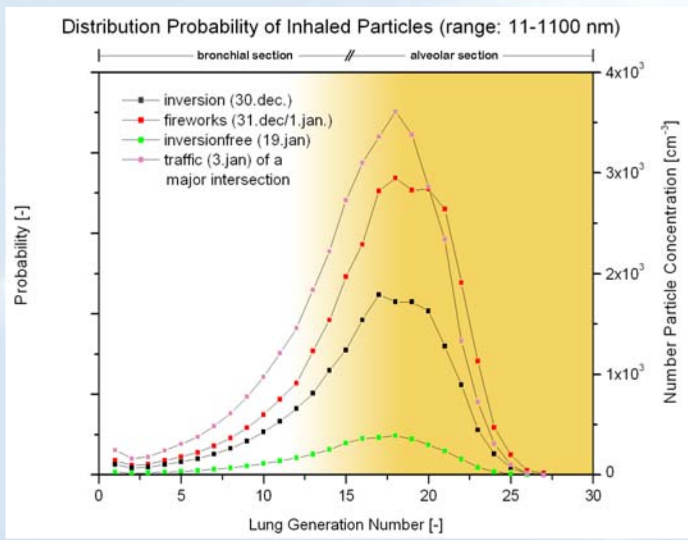

Figure 3: Modeled lung deposition patterns of various aerosols using the Monte Carlo code IDEAL. Plotted are simulations for fireworks, traffic and background measurements.

Conclusion

Although elevated short-term and localized aerosol concentrations readily deposit within the human lung, firework-related increase in aerosols (Barman *et al.*, 2008) or brief exposure to accumulated traffic-related aerosols are much better tolerated than elevated background aerosol-concentrations as can be found during periods of inverse temperature conditions. The lasting effect of prolonged exposure due to inversion events pose a serious challenge to susceptible individuals with a history of respiratory difficulties.

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