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REMOTE SENSING OF AIR POLLUTION BY LIDAR

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Abstract - Recent progresses in remote sensing of atmospheric pollution using the Lidar technique are presented. 2D and 3D analysis of NO, NO₂, SO₂, and O₃ were performed at high sensitivity under emission and immission conditions. Most attractive results were obtained over large urban areas like Lyon, Stuttgart, Zürich, Geneva and Berlin. New Lidar systems, based on self-developed Flashlamp-pumped Ti:Sapphire lasers are also presented.

The atmospheric equilibrium depends on hundreds of chemical species, but only few of them are directly emitted and considered as main pollutants. All the others are trace constituents being nevertheless of outstanding importance for the chemical dynamics in the atmosphere. Since e.g. smog situations do not only depend on the occurring emissions but also in a crucial way on the meteorological situation, the physical dynamics in the atmosphere is of the same importance for the description of air pollution as the chemical aspect. For those reasons, atmospheric physics, chemistry and meteorology must each contribute in an interdisciplinary manner in order to find adequate solutions for a given problem. As a consequence, the conventional techniques of air pollution control do not meet our needs any more. After years of scientific as well as technical development, some remote sensing techniques are now ripe for routine measurements [1]. Thus, complex phenomena like urban smog or acid rain can be investigated by continuous monitoring over a large and 3D scale.

The Lidar technique (Light Detection And Ranging) is one of the most promising remote sensing techniques [2,5]. Two laser pulses of different wavelengths are sent into the atmosphere, one wavelength being highly absorbed by a specific pollutant and the other one used as reference. By measuring the difference between both backscattered intensities as a function of time (like a dual color optical Radar), the concentration of the detected pollutant is monitored range-resolved. A simple steering of both superposed laser beams towards all directions leads then to 3D maps of mixing ratios.

The mobile Lidar system that we developed uses excimer pumped dye lasers as light source and a 40 cm Newtonian telescope for light collection. Interference filters of narrow bandwidth protect the photomultiplier tube from background radiation. The DIAL system is implanted in a van of less than 3500 kg total weight, which allows high mobility. The high repetition rate of the system and a new technique combining atmospheric backscatter and topographic targets allowed very low detection limits (about 500 ppt) over large optical paths (up to 20 km). In numerous field campaigns were monitored SO_2 , NO , NO_2 , and O_3 in immission or emission [3-6].

In the following, some expressive examples shall illustrate the possibilities of the Lidar technique. Figure 1 represents a 3D mapping of the NO_2 mixing ratio over a chemical factory. The high spatial resolution (1.5 m) allows the monitoring of macro-scale turbulences inside the plume. In order to be representative of the plume spread, the analysis must however be performed at a timescale of some minutes [5].

Figure 1 : NO_2 Emission from a chemical factory, 3D profile (in ppm).

Since according to legislation emission is already directly controlled inside the chimney stack, the main interest in Lidar application has become immission control. Monitoring urban traffic is an ideal case for Lidar measurements. For this purpose, a new technique has been developed in order to efficiently detect NO and even detect simultaneously NO and NO_2 [3]. The first NO mapping over a city has been performed in Lyon in 1988. Using both topographic targets lying on the peninsula and atmospheric backscatter, we obtained a detailed picture of the immission load during the rush hours. As exhibited in figure 2 the large main axes showed rather low NO mixing ratios (compare the sectors of 16 and 17 ppb), obviously because they were better ventilated than the narrow streets, which showed much higher values (102 and 98 ppb). Strong effects of topology and local meteorology have been observed by comparing this study with other cities like Stuttgart and Geneva [6].

Figure 2 : Vertical NO profile above the center of Lyon [6].

Figure 3 : Diurnal variation of O₃ in a rural area nearby Zurich in summer

A severe problem has recently emerged as the so-called "summer smog". Tropospheric ozone is formed in a photochemical cycle starting with NO₂, which is dissociated by light with wavelengths shorter than about 430 nm. An oxygen atom is formed and reacts with an oxygen molecule to build O₃. Finally, as ozone is a strong oxidant it can react with nitric oxide and closes the cycle again by formation of NO₂. A typical diurnal ozone measurement is shown in Fig. 3. Ozone is considered as a health hazard, when it exceeds 120 ppb. Note the last peak in the evening which is due to ozone transport during a thunderstorm.

Figure 4 : Vertical SO₂ profiles above Berlin in winter.

Berlin is still divided by the different use of fossil fuels in the former western and eastern parts of the city. Fig. 4 shows three vertical profiles measured in Wedding (West) and Mitte (East). As shown, the SO₂ mixing ratio is highest just above the roofs and reaches 140 ppb in Mitte, but only about 40 ppb in Wedding. Of course, at higher altitudes, the differences were smeared out by better mixing.

The future of Lidar monitoring of air pollution is constituted by routine measurements. This implies however a particular effort for reaching a high level of reliability and simplicity of operation. We therefore centered our present investigations on the development of new tunable solid state lasers. We constructed a high energy (500 mJ) Flashlamp-pumped Titanium:Sapphire (Ti:Al₂O₃) laser, which after frequency doubling, tripling or mixing represents the ideal tool for future Lidar systems. A new routine station will be placed in the center of Berlin at the top of the Charité Hospital and will be able to monitor air pollution up to about 10 km range. By monitoring of the main air pollutants as well as the aerosol size distribution, we plan to analyze smog situations thoroughly in order to find new ways of prevention.

The presented work has been performed in the group of Prof. Wöste, with the collaboration of H.J. Kölsch, P. Rairoux, H. Kneipp, J. Kolenda, B. Stein, and D. Weidauer.

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