Meteorologically adjusted long-term trends (1991 to 2004) of PM10 in Switzerland

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INTRODUCTION

Ambient particulate matter (PM) is of great concern because of their known adverse effects on human health. As a consequence, air quality standards for PM have been implemented in many countries. In Switzerland, daily (50μg/m^3) and annual standards (20μg/m^3) for PM10 were promulgated in 1998. A large part of the Swiss population live in an area where the annual standard for PM10 is exceeded [1]. Violation of the daily standard mainly occurs during high-pressure weather conditions in winter, when vertical mixing of ground-level air masses is reduced.

Analysis of the long-term trends of air pollutants is a well established approach to assess the impact of emission control strategies. However, meteorological conditions, seasonal variations and weekly cycles can have a strong influence on pollutant concentrations and can easily mask long-term changes. The effect of these influencing factors should therefore be removed before long-term trends are estimated. In this work, a regression modelling approach is used to estimate the meteorologically adjusted long-term trends of PM10 at thirteen sites in Switzerland during the period from 1991 to 2004.

METHOD

Daily PM10 data from the Swiss national air pollution monitoring network (NABEL) are used in this study. Up to 1997, the mass concentration of total suspended particulates (TSP) was measured instead of PM10. However, the TSP concentrations were converted into PM10 by scaling with a factor that was determined from parallel measurements of TSP and PM10 during the whole year of 1997. Meteorological data originated from NABEL and from ANETZ stations operated by MeteoSwiss. Additional explanatory variables representing the vertical stability of the troposphere, the frontal passages and the synoptic situation were derived from radio soundings taken in Payerne and Milan and the Alpine Weather Statistics [2].

It is assumed that the PM10 time series can be represented as the sum of a long-term component, a seasonal cycle, a weekly cycle, and important meteorological variables. A generalized additive regression model is used to estimate the association between the daily mean PM10 concentration and the explanatory variables. Generalized additive models are used because of its capability to represent nonlinear relationships between PM10 and influencing variables. Transformation of daily PM10 concentrations into their logarithms was necessary to obtain residuals that are Gaussian distributed with constant variance. However, meteorologically adjusted annual PM10 values can easily be derived from the estimated model parameters.

RESULTS AND CONCLUSIONS

The specified models are capable to explain 54 to 69% of the variance of ln(PM10). Meteorological variables with a significant influence on ln(PM10) are temperature, wind speed, precipitation, relative humidity, radiation, atmospheric pressure, as well as sunshine duration, number of days after frontal passage, vertical gradient of potential temperature, and the convective boundary layer height. A description of the latter set of variables is given in [3].

Meteorology adjusted annual PM10 in Switzerland are linearly decreasing until the end of the 1990's, since then they are constant. From 1991 to the end of the 1990's, negative trends of about -2μg/(m^3 yr) are obtained at kerbside sites. At urban and suburban sites as well as at rural sites, the observed PM10 reductions are smaller (about -1 μg/(m^3 yr) and -0.5 μg/(m^3 yr), respectively). This indicates that primary PM10 emission from road traffic was significantly reduced during this period. However, constant meteorologically adjusted PM10 levels during the last few years indicate that implementation of further reduction measures is necessary for a continuing reduction of the PM10 burden.

ACKNOWLEDGEMENTS

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Introduction

Ambient particulate matter (PM) is of great concern because of their known adverse effects on human health. A large part of the Swiss population live in an area where the annual standard for PM10 (20μg/m^3) is exceeded [1]. Violation of the daily standard (50μg/m^3) occurs mainly during high-pressure weather conditions in winter, when vertical mixing of ground-level air masses is reduced.
Analysis of the long-term trends of air pollutants is a well established approach to assess the impact of emission control strategies. However, meteorological conditions, seasonal variations and weekly cycles can have a strong influence on pollutant concentrations and can easily mask long-term changes. The effect of these influencing factors should therefore be removed before long-term trends are estimated. In this work, a regression modelling approach is used to estimate the meteorologically adjusted long-term trends of PM10 at thirteen sites in Switzerland during the period from 1991 to 2004.

Method

Daily PM10 data from the Swiss national air pollution monitoring network (NABEL) were used in this study. Meteorological data originate from NABEL and from ANETZ stations operated by MeteoSwiss. Additional explanatory variables representing the vertical stability of the troposphere, the frontal passages and the synoptic situation were derived from radio soundings taken in Payerne and Milan and the Alpine Weather Statistics [2].
It is assumed that the PM10 time series can be represented as the sum of a long-term component LT, a seasonal cycle S, a weekly cycle W, and important meteorological variables M_i, i=1...n. A generalized additive regression model of the form

$$\ln(PM10_t) = \alpha + \sum_{i=1991}^{2004} \mu_i LT_{it} + f(S_t) + \sum_{i=1}^{7} \beta_i W_{it} + \sum_{i=1}^{n} f(M_{it}) + \varepsilon_t$$

is used. The terms in above model equation denote the following:

$PM10_t$: PM10 concentration at day t

α: model intercept

LT_{it}: indicator for the year of measurement. LT_{it}=1 when day t is in i-th year, otherwise LT_{it}=0

μ_i : effect of i-th year on ln(PM10)

$f(S_t)$: nonparametric function that models the relationship between ln(PM10) and season, represented here by the month of the year

W_{it}: indicator for the day of week. W_{it}=1 when day t corresponds to the i-th day of week, otherwise W_{it}=0

β_i: effect of i-th day of week on ln(PM10)

$f(M_{it})$: nonparametric function that models the relationship between ln(PM10) and meteorological variables

Transformation of ln(PM10) back into concentration units leads to a multiplicative model. The $\exp(\mu_i)$ are then factors representing the average effect of year i on PM10. For comparison with the observed annual PM10 values ($PM10_i$, i=1991…2004), meteorologically adjusted annual PM10 are expressed as

$$PM10_{adj\,i} = \exp(\mu_i) \cdot \frac{\sum_{i=1}^{n} PM10_i}{\sum_{i=1}^{n} \exp(\mu_i)}$$

Results

Use of generalized additive regression to model ln(PM10) was capable to explain 54 to 69% of the variance of ln(PM10) (Table 1). Meteorological variables with a significant influence on ln(PM10) are temperature, wind speed, precipitation, relative humidity, radiation, atmospheric pressure, as well as sunshine duration, number of days after frontal passage, vertical gradient of potential temperature, and the convective boundary layer height. A description of the latter set of variables is given in [3].

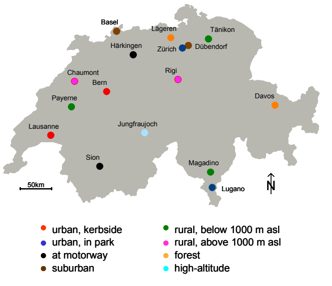

Figure 1: Sites and site types of the Swiss national air pollution monitoring network NABEL.

Figures 2 and 3 show examples of the estimated influence of significant explanatory variables to PM10.

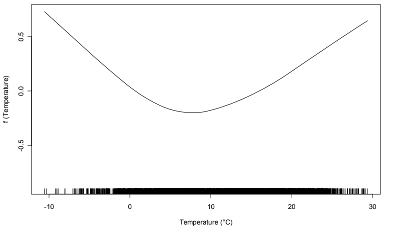

Figure 2: Estimated influence of temperature on ln(PM10) at the urban background site in Zurich, Switzerland. Similar to all other considered measurement sites, PM10 values in Zurich tend to be elevated at low temperatures (mainly due to reduced vertical mixing) as well as at high temperatures (probably due to secondary PM10 formation). At moderate temperatures, PM10 levels tend to be lower.

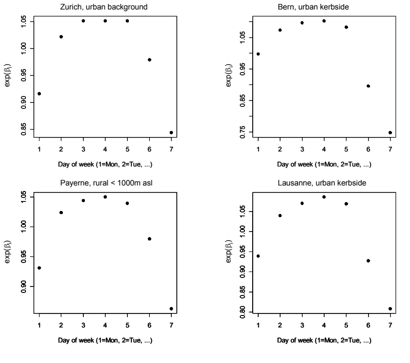

Figure 3: Estimated weekly cycle. Average PM10 levels are lowest on Sundays, when traffic is generally reduced and heavy duty vehicles are banned from Swiss roads. However, it is rather surprising that average PM10 levels on Mondays are clearly lower than on the other days of the week (except Sundays), except at roadside sites, where PM10 values are on average lower on Saturdays than on Mondays. It seems that the reduced emissions of primary PM10 and/or precursors on Sundays have an effect on PM10 during the following day.

Trends

Meteorology adjusted annual PM10 in Switzerland were linearly decreasing until the end of the 1990's, since then they are rather constant. Trends of annual PM10 are therefore estimated by piecewise regression. The trends are defined by two slope parameters and a break-point which are estimated simultaneously.

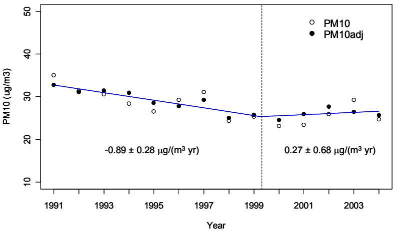

Figure 4: Observed (open circles), meteorologically adjusted annual PM10 (closed circles) and estimated trends at the urban background site in Zurich.

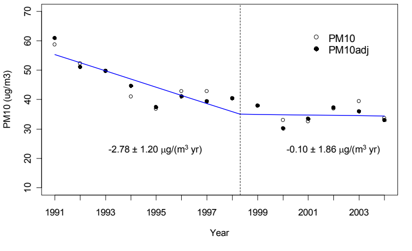

Figure 5: Observed (open circles), meteorologically adjusted annual PM10 (closed circles) and estimated trends at the urban kerbside site in Bern.

***Table 1:** Summary of the trend estimations for meteorology adjusted PM10 from 1991-2004 at different sites and site types of the NABEL network.*

Site	Site type	R^2	Trend 1 μg/m^{3}yr	Trend 2 μg/m^{3}yr	$Year_b$
Bern	urban, kerbside	0.68	-2.78 (±1.20)	-0.10 (±1.86)	1998.3
Lausanne	urban, kerbside	0.68	-2.47 (±0.38)	0.33 (±1.54)	2000.0
Zurich	urban, in park	0.66	-0.89 (±0.28)	0.27 (±0.68)	1999.3
Lugano	urban, in park	0.61	-2.50 (±1.12)	-0.26 (±0.46)	1995.2
Basel	suburban	0.65	-0.93 (±0.44)	-0.02 (±1.06)	1999.5
Duebendorf	suburban	0.69	-0.98 (±0.36)	-0.22 (±1.49)	1998.4
Haerkingen	at motorway	0.69	-1.22 (±0.40)	-0.02 (±0.61)	1998.4
Sion	at motorway	0.68	-1.76 (±0.42)	-0.11 (±0.65)	1998.2
Magadino	rural, <1000m asl	0.62	-1.82 (±0.86)	0.66 (±2.12)	1999.7
Payerne	rural, <1000m asl	0.63	-0.54 (±0.24)	0.39 (±1.12)	2000.5
Taenikon	rural, <1000m asl	0.67	-0.69 (±0.31)	0.06 (±1.21)	1999.7
Chaumont	rural, >1000m asl	0.54	-0.24 (±0.20)	---	---
Rigi	rural, >1000m asl	0.55	-0.38 (±0.32)	0.29 (±1.32)	1999.1

Conclusions

Meteorologically adjusted PM10 levels show a reduced year-to-year variability compared to measured PM10 levels. The high PM10 levels during the extremely dry and warm year 2003 are reduced to usual levels after meteorological adjustment. However, there is still some year-to-year variability the models cannot account for.

- In Switzerland, PM10 levels were constantly decreasing during the 1990's:
  - kerbside sites app. -2μg/(m^3 yr)
  - urban and suburban sites app. -1μg/(m^3 yr)
  - rural sites app. -0.5μg/(m^3 yr)
- Since then, PM10 is constant at too high levels: Implementation of further reduction measures is needed

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