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Analysis of predominantly non-meteorological influences on air pollution in North Rhine-Westphalia, Germany

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Abstract

In the given paper the influences of predominantly non-meteorological effects, i.e. emission cycles, economic procedure and traffic, on air pollutants are studied out for different locations in North Rhine-Westphalia, Germany. The investigation on weekly cycles of air pollution ('sunday effect') has been realised taking into account the fact that weekend-weekday concentration differences (for instance higher NO concentrations on weekdays) are not caused by meteorological but non-meteorological influences. However, as far as the study covers both urban and rural sites, meteorological influences should also be concerned with.

1. Introduction

Diurnal cycles of each pollutant exhibit different paths due to the origin of the pollutant. NO and NO_2 closely related to the traffic show peaks early in the morning and late in the evening due to the traffic build-up. The only difference in the diurnal shape of these pollutants is that the morning peak of NO is much higher than the one of NO_2 probably due to the longer life span of the latter one (Kiss et al., 2005). In contrast to them, O_3 which is a secondary pollutant shows peaks late in the morning or in the afternoon (Pudasainee and Sapkota, 2006). On weekly basis NO and NO_2 concentrations are significantly high on weekdays compared to weekends (vice versa for ozone). This effect called 'Sunday effect' is a clear manifestation of anthropogenic influences on the air pollution (Murphy et al., 2008). Existence of seasonal cycles is due to the atmospheric state and conditions for the pollution diffusion (Debaje and Kakade, 2006). Hence the necessity of investigation of also meteorological parameters arises, which has been carried out via applying regression analysis, later having estimated the accuracy of regression model by cross-validation system. These temporal cycles of pollutants have been observed in all three stations with extensional differences.

2. Research area, data and methods

Within the frames of the given paper temporal cycles on diurnal, weekly and seasonal basis of different air constituents are studied for the research area North Rhine-Westphalia. It has 18 million inhabitants, covers an area of 34,086 km^2 and is characterized with traffic density (http://www.nrwinvest) as well as high degree of industrialization.

Here we are considered with the following types of pollutants - NO, NO_2, and O_3 - and the meteorological parameters as temperature, radiation, precipitation, humidity, wind speed and direction. All the data running from 1981 up till 2007 are obtained from 3 stations provided by the North Rhine-Westphalia state Environment Agency (LANUV NRW), the characteristics of which are industrial, traffic and background.

1. Industrial station Duisburg-Walsum (WALS) is characterized with high dense industrial factories - coal burning factories, coking plant, paper and iron proceeding factories.
2. Traffic station Essen East (VESN) is located in residential cultivation, 1 km away from city centre Essen. A high dense highway passes close to the station.
3. Background station Horn-Bad Meinberg Egge (EGGE) is located on the west slope of Paderborn State forest. Although the character of the station is background, two highways are passing nearby, one 1 km east, and the other 100 m west.

All the data we are concerned with are half-an-hour means, which have been averaged using descriptive statistics. Later on they have been aggregated on daily and weekly basis. Student's t - and F - test of significance have been applied to evaluate the significance of the pollution concentration difference between weekdays and weekends.

3. Results

The results are presented in the following manner: temporal cycles of NO (weekly cycles of NO_2 are not shown here because of the relative similarity to NO concentration pattern), O_3 concentrations at industrial, traffic and background stations, comparison among the stations, and time trends for weekdays and weekends separately.

3.1 Industrial and traffic stations (WALS and VESN)

The data of both industrial and traffic stations show clearly defined diurnal and weekly cycles of NO and NO_2 concentrations. *Diurnal pattern* of NO and NO_2 - concentrations exhibits double-wave shape with maximum values at 7-9 am and at 5-8 pm due to the rush-hours. This is the case only for working-days (WY), whereas on weekends (WD) the peaks are observed at afternoon and evening hours probably due to leisure activities of people (Fig. 1a).

On weekly basis we see that not only time differences of NO maximum concentrations between WYs and WDs occur, but also absolute average value on WDs is sufficiently low (by 40 %) then on WYs. In contrast to significant difference ($\alpha = 0.01$) between WYs and WDs there is no difference within weekdays except Friday, when the second peak is not clearly defined because of the working day being short.

Within seasonal comparison the only difference is observed in much higher concentrations at the evening hours in winter (Fig. 1b) compared to the summer season (Fig. 1c), which depends on the prevailing weather conditions; higher values in winter might refer to atmospheric stability with frequent temperature inversions.

All the assumptions above carried out for nitrogen oxides are totally the contrary for O_3. Therefore rises the necessity to investigate the temporal cycles of ozone as well, because they provide deeper understanding how the latter responds to changes in anthropogenic emissions from WYs to WDs (Pun and Seigneur, 2001). Production of O_3 decreases as NO concentration increases ($r = -0.67$), and as far as NO concentration increases on WYs, O_3 concentrations are significantly lower on WYs compared to WDs. (Figs. 2 and 3).

Although the precursors often originate in urban areas, wind can carry them at the distance of 100's kms causing ozone formation to occur in far remote regions as well. Hence we will include meteorological parameters to investigate pollution in rural areas as well. Namely O_3 gets its higher values when temperature and radiation do so ($r_{ozone, rad} = 0.89$; $r_{ozone, temp} = 0.81$). These assumptions are implied to explain the diurnal and seasonal paths of O_3: higher values on diurnal basis occur at afternoon (3 - 5 pm) and on seasonal basis in summer (Fig. 3c) compared to winter (Fig. 3b).

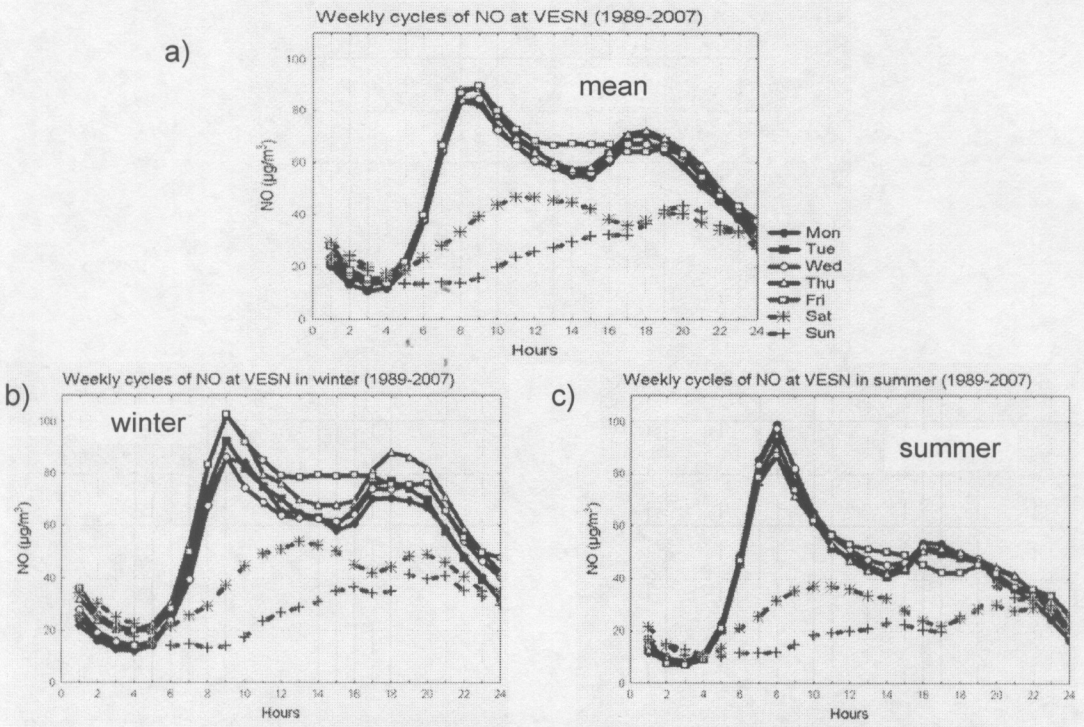

Fig. 1: Diurnal, weekly and seasonal cycles of NO concentrations at traffic station Essen (VESN; 1989-2007) for the whole period (a), winter (b) and summer (c) seasons

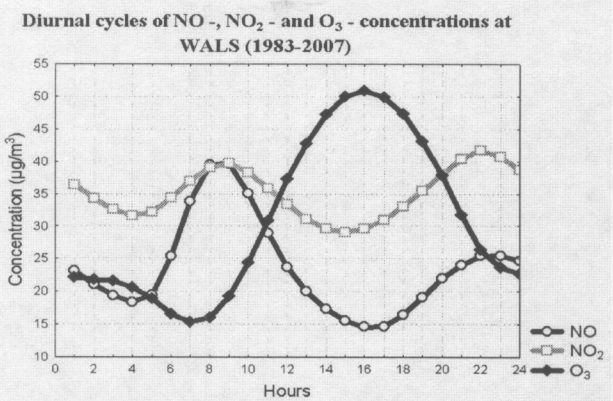

Fig. 2: Diurnal cycles of NO, NO_2 and O_3 concentrations at industrial station Walsum (WALS: 1983-2007)

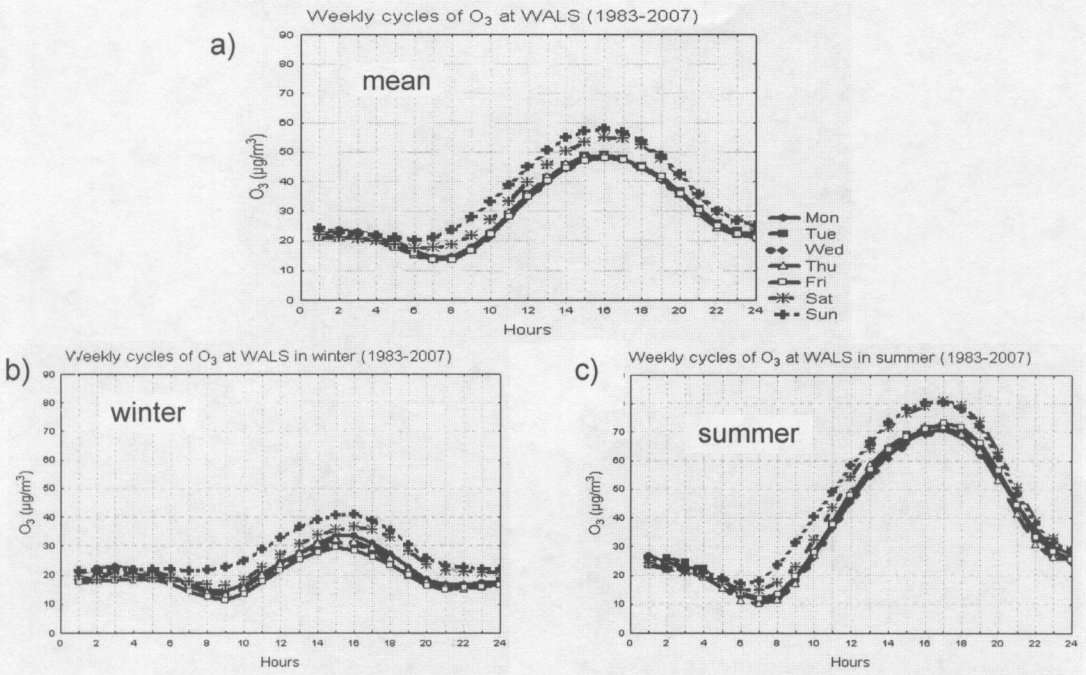

Fig. 3: Diurnal, weekly and seasonal cycles of O_3 concentrations at industrial station Walsum (WALS; 1981 - 2007) for the whole period (a), winter (b) and summer (c) seasons

The given results for NO, NO_2 and O_3 temporal cycles can be transferred to the forest station Egge (EGGE) with some differences: Beyond lower absolute average NO and NO_2 as well as higher O_3 concentrations, the main difference is that the peak of NO occurs later compared to the traffic and industrial stations indicating the transport of the pollutants.

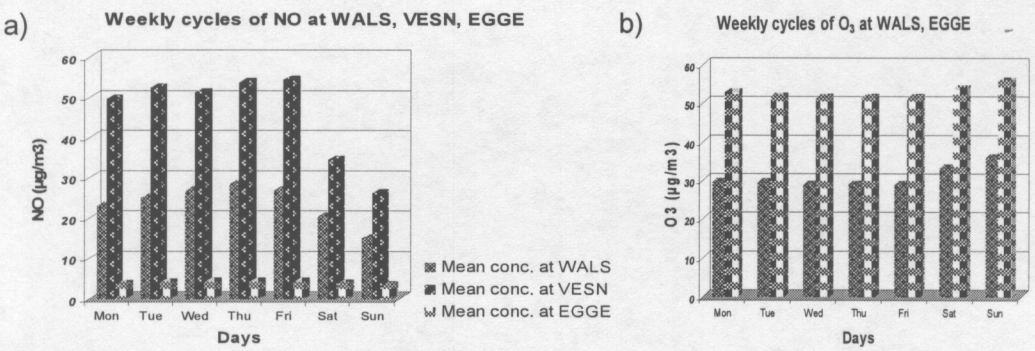

Fig. 4: Comparison of weekly cycles of NO and O_3 concentrations among industrial (WALS), traffic (VESN) and background (EGGE) stations (1989-2007)

3.2 Comparison of weekly cycles of NO, NO_2 and O_3 concentrations among industrial, traffic and background stations

As to the comparison of pollutants weekly cycles among three stations we see that NO exhibit clearly defined late weekday (Thursday, Friday) peaks (Fig. 4) in contrast to O_3 being higher on WDs. The only difference among the stations is absolute average values of the nitrogen oxides being higher especially at traffic station and ozone being higher at background station. The latter is due to the fact that ozone concentration depends on the NO_2/NO ratio. With high NO concentrations at traffic and industrial stations, the NO_2/NO ratio remains small, i.e, even in intense sunlight only a little ozone is formed (Michaelis, 1997).

3.3. Time trends

After getting diurnal and weekly patterns of the pollutants for each station, annual trend for pollutants has been studied integrating WYs and WDs separately for the whole period of time (1989-2007). As Fig. 5a shows not only the WY and WD NO concentrations decreased but also their difference did so because of the successful use of catalyst technology in vehicles starting from the early 1990s (Mayer, 1999). And as far as heavy-duty vehicles are mainly not in function on weekends the decrease of pollution concentration especially on weekends is more sufficient which explains the greater slope of the WD curve and decrease of the WY-WD difference.

a) b)

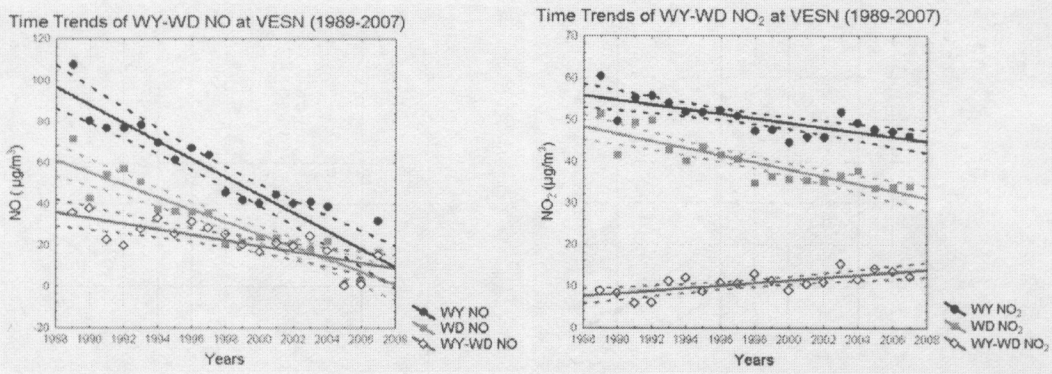

Fig. 5: Time trends of weekdays (WY) – weekends (WD) for NO (a) and NO_2 (b) concentrations at the traffic station Essen (VESN; 1989 - 2007)

But NO_2 pollutant shows some differences (Fig. 5b): although decrease of annual concentration is observed both on WYs and on WDs, the difference of them shows an increase which can be explained with the fact that the use of catalysts was not that sufficient for the reduction of NO_2 because not only secondary but also primary NO_2 emitting vehicles (http://de.wikipedia.org/wiki/Fahrzeugkatalysator) were largely introduced in Germany at the mid of 1990s.

4. Conclusions

NO and NO_2 concentrations on the diurnal basis showed high values at the morning and evening hours, on the weekly basis at late weekdays, and on the seasonal basis in winter (contrary for ozone). Weekday (WY) - weekend (WD) concentrations of the pollutants exhibited significant differences at all the stations. Not only WY and WD concentration of NO, but also their difference decreased in annual cut, but for NO_2 although a decrease on WYs and WDs was observed the difference has increased.

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