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Near surface carbon dioxide within the urban area of Essen, Germany

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ABSTRACT

The aim of this investigation was to determine the allocation between carbon dioxide concentrations, by mobile measurements at 1.5 m a.g.l., within the urban canopy layer regarding different conditions: anticyclonic and cyclonic weather situations, on weekdays, at different times of the day and in different seasons. During winter 2002/2003 (December–February) and summer 2003 (June–August) 20 high frequency spatial and temporal mobile measurements of carbon dioxide were taken in the city of Essen (51° 28′N, 7° 0′E, North Rhine-Westphalia, Germany). The route of the taken measurements started in the southern part of the city and ended after 63 km in the north of Essen, considering all different kinds of its land utilization. The contribution of motor vehicles to the carbon dioxide concentration was being determined by calculating the relation of carbon dioxide to other atmospheric substances, such as CO, NO, NO_2 and O_3. All atmospheric substances were captured at the same time and height with a measurement frequency of 1 Hz and a maximum travel speed of 30 km h^{-1} (8 m s^{-1}). The results of each mobile measurement were condensed to average values for homogeneous route sections. This facilitated a comparison of the urban CO_2 concentration between the CO_2-data of a rural station and the results of a base line station maintained by the Federal Environmental Agency (UBA). With assistance of different statistical methods it was possible to testify that the determined CO_2-data are representative for the situation of the air quality in the city of Essen. The results of this investigation have shown that it is neither generally possible to describe the urban area as a permanent anthropogenic source for CO_2 nor to call it an urban CO_2 dome as it is often mentioned in literature (e.g. Idso et al., 1998, 2001). A comparison of the carbon dioxide mixing ratio of the city of Essen and the rural station, maintained by the Dept. of Applied Climatology and Landscape Ecology, demonstrated that the city exceeds the rural station for less than 30% per season.

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1. Introduction

The global concentration of atmospheric carbon dioxide (CO_2) has increased from about 280 ppm, the pre-industrial revolution level (Leuenberger et al., 1992), to over 370 ppm (Bhattacharya, 2004). Since the first carbon dioxide measuring stations were started up in 1957/1958 (Geophysical Year) at Mauna Loa, Hawaii and at Antarctica (Pales et al., 1965; Brown et al., 1965), a global network of carbon dioxide measuring stations was founded, called "Carbon Cycle Greenhouse Group" (CCGG). This network consists of CO_2-stations on- and off-shore, also maintained by aircraft. So far, only few publications have dealt with the CO_2 problem in urban spaces. The main focus of these investigations laid upon flux measurements (e.g. Offerle et al., 2001; Vogt et al., 2003) and the analysis of stable carbon isotopes to determine the CO_2 sources (e.g. Clarke-Thorne et al., 2003; Pataki et al., 2003). Up to now, the number of investigations in cities with the aim of determining the distribution of urban CO_2 has been very low. Most of them were carried out with the aid of punctual measurements (e.g. Woodwell et al., 1972; Mayer et al., 1991; Soegaard et al., 2003). The fewest publications were based on mobile measurements to determine the typical inhomogeneous fields of emission within urban spaces (e.g. Shorter et al., 1998; Idso et al., 1998, 2001; Bukowiecki et al., 2002; Henninger et al., 2004). Since these investigations were only made over a short period, it was impossible to get representative statements about the atmospheric CO_2 concentration concerning types of land utilization typical for cities.

2. Purposes

The aim of this investigation was to determine the distribution of carbon dioxide within the urban canopy layer. It should be proven how the urban carbon dioxide is influenced by spatial variations of different types of land utilization and in the course of the seasonal change of meteorological conditions. Until now, the main focus of measuring CO_2 in urban spaces was predominantly

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monitoring carbon dioxide within the urban boundary layer (so-called tall-tower measurements), above rooftop-level of the particular measuring location (Woodwell et al., 1972; Aikawa et al., 1993; Nasrallah et al., 2003). Less was done within the urban canopy layer.

Selective monitoring CO_2 at one site enables a highly frequented temporal solution possible for one homogeneous field (Soegaard et al., 2003). But in urban areas there are also inhomogeneous fields of emission. These can only be determined by mobile measurements solving the problem of missing area related data, although it is possible to solve the disadvantage of low temporal solutions by a high quantity of mobile measurements (Kuttler et al., 2002).

In addition to the mobile measurements a rural CO_2 station determined highly temporal CO_2 concentration continuously.

3. Measuring site

The analysis was conducted in the city of Essen (51°28′N, 7°0′E; North Rhine-Westphalia, Germany). Since it is part of the German conurbation called "Ruhrgebiet" with about six million inhabitants, Essen (588.000 inhabitants, 2004; $A = 210\ km^2$) is considered as a typical conurbation city concerning its structure of anthropogenic carbon dioxide emissions (Table 1). As it was expected, most carbon dioxide is emitted by the energy production in Essen. The private sector is on second place, ahead of the industrial and transport sector, because of the high consumption of hard coal for private heating in the whole "Ruhrgebiet" and also in Essen.

The route of the taken measurements started in the southern part of the city (Essen-Kupferdreh – measuring point 1) and ended after 63 km in the north of Essen (Essen-Altenessen – measuring point 61), considering all kinds of its land utilization which are part of the urban area (Fig. 1). Also shown is the CO_2 rural station within an agricultural field in the southwest of Essen maintained by the Dept. of Applied Climatology and Landscape Ecology (black item, Fig. 1). This station was used for the comparison of air quality and meteorological values determined throughout the mobile measurements.

4. Measuring period

The mobile measurements of carbon dioxide were taken during winter 2002/2003 (December–February) and summer 2003 (June–August) regarding different conditions:

- predominantly during clear and calm weather situations ($v \leqslant 1.5\ m\ s^{-1}$),
- for comparison also during cyclonic weather situations ($v > 1.5\ m\ s^{-1}$),
- on weekdays (20 measurement trips),
- at different times of the day (4 am–7 am; 10 am–1 pm; 1 pm–4 pm; 7 pm–10 pm; 11 pm–2 am),
- during different seasons to observe the influence of the phases of vegetation, mainly in summer, or the contribution of domestic fuel in winter on the urban CO_2 in the urban canopy layer of Essen.

Primarily, the decision for the times of mobile measurements was influenced by the daily rush-hour in Essen. So the transect was driven before (4 am–7 am resp. 1 pm–4 pm), respectively after (10 am–1 pm resp. 7 pm–10 pm) the most vehicular traffic. This guaranteed the opportunity of having a homogeneous traffic density along the measuring route. There were also measurement trips made between 11 pm and 2 am, the transition time from the first to the second part of the night. With assistance of these five measuring times the natural diurnal variations in CO_2 concentration of the air, aroused by the natural gas-exchange cycle of the biosphere (photosynthesis, respiration of plants, CO_2 soil exchange) could be represented. Likewise, it was possible to have a look on the atmospheric boundary layer conditions in connection with the times of the day and its influence on the urban CO_2.

Table 1
Carbon dioxide emissions in Essen, Germany, dependent from different consuming sectors.

Energy production	2.2 Mio. t CO_2a^{-1}
Private sector	1.4 Mio. t CO_2a^{-1}
Industrial sector	1;17 Mio. t CO_2a^{-1}
Transport sector	1 Mio. t CO_2a^{-1}

5. Methods

The measurement trips were made using the mobile laboratory of the Dept. of Applied Climatology and Landscape Ecology, University of Duisburg-Essen, Campus Essen. In addition to CO_2, the air quality indicators CO, O_3, NO and NO_2 were measured 1.5 m above ground level at the same time and height. The meteorological values air temperature, relative humidity (2 m a.g.l.) and global radiation (3.5 m a.g.l.) were also recorded. The analysis of carbon dioxide and other air quality indicators with the same assumptions (time and height) enabled a reconstruction of the quantitative influence on CO_2 by anthropogenic sources. The different measurement methods are summarized in Table 2.

The mobile laboratory travelled by a maximum speed of $30\ km\ h^{-1}$ ($8\ m\ s^{-1}$) and with a measurement frequency of the analyzers of 1 Hz. So every 8 m one measured value was recorded. In spite of the known delay time of the analyzers (e.g. $CO_2 = 13$ s) and due to a temporal correction after the measurement trips it was possible to relate one recorded value to its part of the measuring route where the carbon dioxide was determined.

In view of the rapid fluctuations of trace element concentration (e.g. caused by the change of land utilization, the structure of housing, the traffic density or different climatopes along the transect) arithmetic average values of homogeneous road sections were calculated. Every road section is characterized by a homogeneous type of land utilization with an average length of 940 m (range from 800 m to 950 m) (Henninge et al., 2004).

It was necessary to keep a "safety distance" of more than two meters to have low influences by the exhaust plume of automobiles in front of the mobile laboratory (Clifford et al., 1997). Affected data were filtered out, which occurred by traffic jam because of road works, junctions and traffic lights. Indeed this filtering of the data did hardly change the determined concentration with or without traffic hold-up ($\alpha > 0.1$, $R^2 = 0.96$) (Henninger et al., 2004).

Considering the results of each mobile measurement trip to average values of homogeneous route sections facilitated a comparison of the urban CO_2 concentration to the CO_2-data of the rural measuring station (black item, Fig. 1). Differences between the urban and rural carbon dioxide mixing ratio could be verified and the percentage diverge was being indicated. In cause of $z_0 = 0.11$ m, wind could flow unaffectedly to the rural measuring station from all directions. Data of z_0 were calculated by the equation of Zsmarsly et al. (2002). So it was possible to calculate the CO_2 concentration dependent of wind direction and it could be reconstructed if the advective flow had its origin in the urban plume or above the agricultural fields near the station (see Section 7.1).

6. Reproducibility of data

Statistical methods should testify if the determined CO_2-data were representative for the situation of air quality in the city of Essen or if the concentration of each trip was a snap-shot. Primarily,

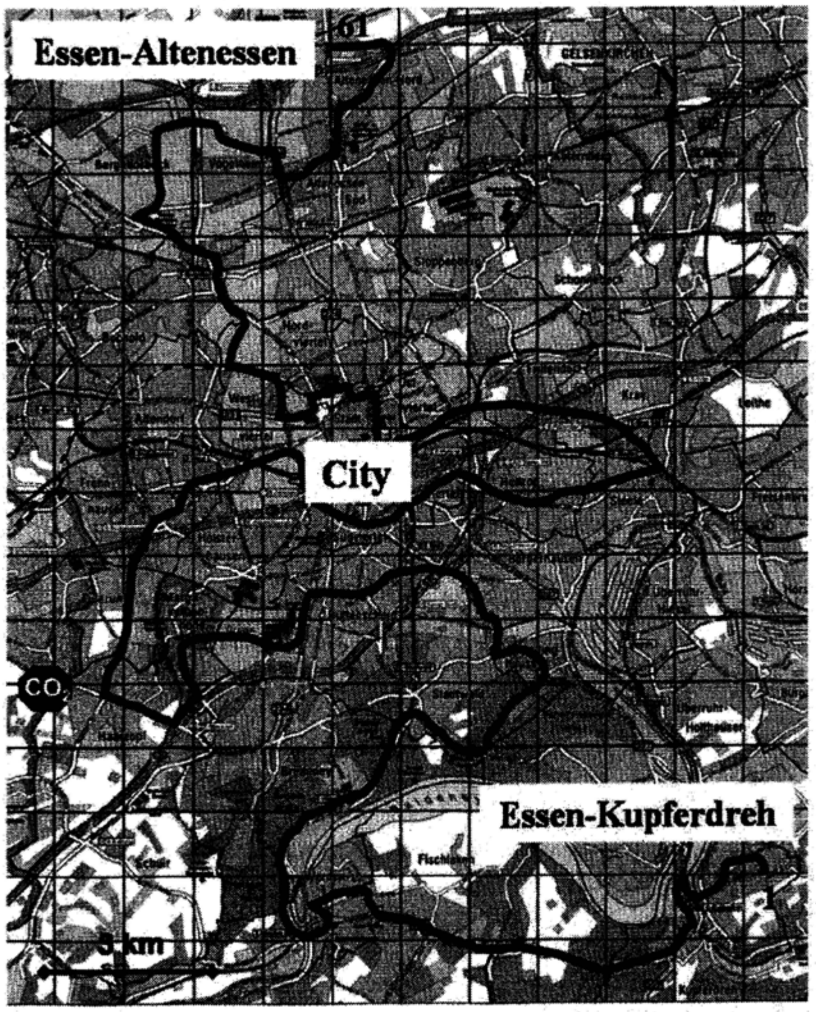

Fig. 1. Street map of Essen (North Rhine-Westphalia, Germany) showing the location of the CO_2 transect and the CO_2 rural station (1; 61 = beginning resp. end of the measuring route).

Table 2
Physical and chemical methods of measuring trace elements.

Trace elements	Measurement method
CO_2, CO	IR absorption
NO, NO_x	Chemoluminescence
O_3	UV absorption

the cluster analysis, based on calculating the *Euklidean Distance*, should give information about similarities of the behaviour of carbon dioxide along the transect between the accomplished measurement trips.

Fig. 2 (summer values) offers five separate clusters altogether identical with the five different times of measuring, mentioned in part 4.

A comparison of the measurement trips, which were connected in one cluster, presents a uniform allocation of CO_2 along the transect (Fig. 3).

Significance tests calculated by *student-test* presented a validation.

Measurements taken at the same time of the day and different dates display no significant differences ($\alpha > 0.5$, Fig. 3), whereas trips of diverse times show a significance of $\alpha < 0.05$, respectively a high significance of $\alpha < 0.01$. These results were proven during measuring trips in summer as well as in winter which demonstrates that there is, dependent on the time of the day, a recurrent CO_2-pattern along the transect. That is why a reproducibility of the behaviour of carbon dioxide is necessarily given and enables an allocation of the different kinds of land utilization along the transect.

7. Results

7.1. Comparison between urban and rural CO_2

The comparison of mobile determined urban carbon dioxide and simultaneously measured CO_2 of the rural monitoring station in the outskirts indicates that the average CO_2 concentration of the mobile measurements within the urban canopy layer is always higher than in the rural area. This occurs independently from the seasons and the time of the day. Table 3 shows that the prevailing average values of the city are 8.9%, 6.5%, respectively 11.3% above the values of the rural station.

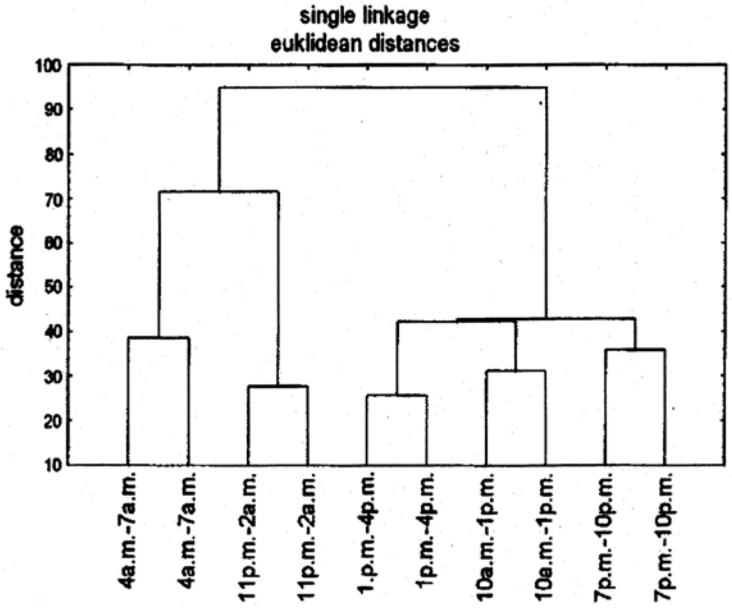

Fig. 2. Cluster diagram of all mobile CO_2 measurements in Essen, North Rhine-Westphalia, Germany (summer 2003; $n = 10$).

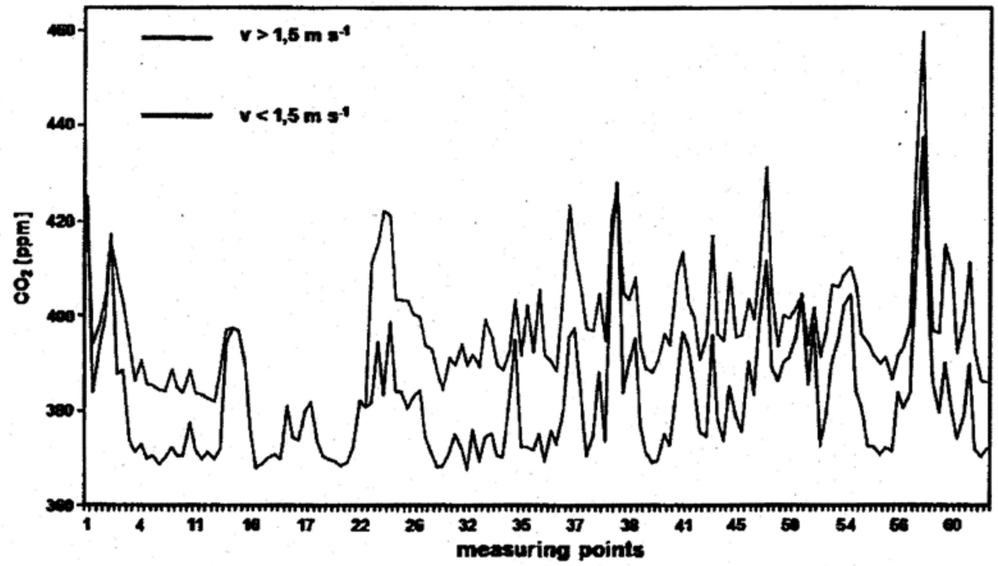

Fig. 3. CO_2 courses ($R^2 = 0.83$) for two different days with two different weather situations, but similar measuring times (10 am–1 pm; summer 2003); black bend = $v \leqslant 1.5$ m s^{-1}; grey bend = $v > 1.5$ m^{-1}.

Table 3
Average CO_2 concentration and standard deviations of the mobile measurements ($\bar{x}_{\text{-urban-}}$ resp. $\sigma_{\text{-urban-}}$) and of the CO_2 rural station ($\bar{x}_{\text{-rural-}}$ resp. $\bar{\sigma}_{\text{-rural-}}$) for the whole measuring period (winter and summer), as well as for summer (2003) and winter (2002/2003) in ppm.

	$X_{\text{-urban-}}$	$\sigma_{\text{-urban-}}$	$X_{\text{-urban-}}$	$\sigma_{\text{-urban-}}$	in %
Measuring period	404	19.44	371	5.67	8.9
Summer	393	17.55	369	8.53	6.5
Winter	415	21.33	373	2.81	11.3

Beneath the time of the day and the stability of the atmospheric boundary conditions, calculated after Pasquill (1961) based radiation and wind speed, one dominant factor of influence is the wind direction. During calms ($v \leqslant 1.5$ m s^{-1}), respectively a wind direction from S to SE, the CO_2 difference between urban and rural concentration could achieve more than 20%, whereas there are minor differences with wind coming from NE to E ($\leqslant 5\%$; $\alpha < 0.05$). Anytime the meteorological conditions arouse such a situation (wind from NE to E; by 15% of the time of the measuring period), the air pollution load was influenced by the trace elements of the urban plume of Essen which were taken along by passing the city. Finally, the rural station recorded an increasing carbon dioxide concentration above normal (Table 4).

Nevertheless, if the periods of influencing the rural carbon dioxide by the urban plume were neglected, the CO_2 concentration of this monitoring station could be accounted as representative. An additional analysis of CO_2-data determined by a base line monitoring station maintained by the Federal Environmental Agency (UBA) only displayed a minimal difference to the ones of the rural station maintained by the Dept. of Applied Climatology and Landscape Ecology (Table 5). So it was possible to consider the CO_2 data determined by the CO_2 rural station as representative for a comparison between urban and rural concentration.

Consequently, the city of Essen did by far not obtain the differences between the urban and rural areas as it has been proven for other cities, e.g. Copenhagen/Denmark (>50%, Soegaard et al., 2003) or Phoenix/USA (70%, Idso et al., 1998).

7.2. Seasonal variations of urban CO_2

It should be proven whether small fluctuations caused by the anthropogenic CO_2 emissions permanently available in urban areas (Takahashi et al., 2001) result in a difference between the urban CO_2 mixing ratio of the warm and cold season (Idso et al., 1998; Nasrallah et al., 2003).

Fig. 4 displays the course of CO_2 along the transect for the winter months (black bend) as well as for the summer months (grey bend). Additionally, there are the average values for both seasons (winter, $\bar{x}_{winter} = 415$ ppm; $\sigma = 21.33$ ppm; summer, $\bar{x}_{summer} = 393$ ppm; $\sigma = 17.55$ ppm). The highly spatial variability of carbon dioxide, which is shown in Fig. 4, is a justification for the determination of CO_2 within the urban canopy layer by mobile measurements and offers the necessity of calculating average values for homogeneous road sections.

The increase of CO_2 concentration in winter, in comparison to the lower ones in summer, is due to several facts:

- increased gasoline consumption caused by automobiles (e.g. cold start),
- additional CO_2 emissions caused by domestic fuel (e.g. private heating with hard coal),
- a reduced plant activity which causes a lower photosynthesis,
- a higher share of CO_2 soil exchange, which is also reduced in winter, but it cannot be absorbed by photosynthesis as much as in summer and
- more stable atmospheric conditions during the measuring times.

7.3. Day- and night-time variations of urban CO_2

The influence of the CO_2 course along the transect, e.g. by domestic fuel in winter or natural gas-exchange by the vegetation in summer, could be displayed more exactly by a differentiation of the measurements into day- and night-time trips. Similar to Fig. 4, there is also a difference between the CO_2 concentration, indeed of day (Fig. 5, dashed bends) and night time measurements (Fig. 5, solid bends). Additionally to the average values for winter day time (upper, dashed grey line; $\bar{x}_{day\_winter} = 402$ ppm; $\sigma = 19.58$ ppm) and night time (upper, solid black line; $\bar{x}_{night\_winter} = 427$ ppm; $\sigma = 23.17$ ppm) Fig. 5 illustrates the values of summer day time (lower, dashed grey line; $\bar{x}_{day\_summer} = 369$ ppm; $\sigma = 15.57$ ppm) and night time (lower, solid black line; $\bar{x}_{night\_summer} = 417$ ppm; $\sigma = 19.54$ ppm).

One reason for the higher concentration during night times could be given by meteorological conditions in summer as well as in winter, which favour a CO_2 accumulation. Stable conditions, registered at different urban monitoring stations within the urban area of Essen, were built up within the second part of the night prior to sunrise as calculated by Pasquill (1961). These conditions, namely additional CO_2 emissions in winter and CO_2 respiration by plants during summer nights, made the carbon dioxide concentration increase. After sunrise the stable conditions of the night started to break down, convective mixing starts. Due to increased wind speed there was a better exchange of the urban atmosphere which is responsible for the decreasing CO_2 concentration. Likewise, there was an increase of plant activity on summer days which acted as a potential CO_2 sink. According to these matters of facts the significant differences between the CO_2 concentration of night- (solid bends) and day-time (dashed bends) are explainable.

The CO_2 course for summer nights (grey, solid bend) reflects the changing types of land utilization along the transect. Most of the displayed CO_2 peaks (black arrows, Fig. 5) were similar to suburban and urban green spaces, respectively spaces which show a high portion of vegetation. It can be noticed that the CO_2 respiration dominated over anthropogenic sources in summer nights because of e.g. low night time traffic density. In comparison to this, the CO_2 course of winter nights (black, solid bend) indicates a relatively constant carbon dioxide level without additionally CO_2. For summer days (dashed, grey line) as well as for winter days (dashed, black line) there were no CO_2 peaks provoked by green spaces in contrast to the night time measurements. Throughout the day, the dominating factors of anthropogenic sources, e.g. high traffic density caused by traffic lights, junctions or road works, were visible (grey arrows, Fig. 5).

Table 4
Average CO_2 concentration of the mobile measurements ($\bar{x}_{\text{"urban"}}$) and the CO_2 rural station ($\bar{x}_{\text{"rural"}}$) in ppm, as well as the average wind speed and wind direction during the different measuring times (summer 2003).

Measuring trip	Time of the day	$\bar{x}_{\text{"urban"}}$	$\bar{x}_{\text{"rural"}}$	WD	WS
1	23:00–02:00	409	375	S-SW	$v \leq 1.5\ m\,s^{-1}$
2	23:00–02:00	408	386	S	$v \leq 1.5\ m\,s^{-1}$
3	10:00–13:00	375	365	SSE	$v > 1.5\ m\,s^{-1}$
4	10:00–13:00	384	364	S	$v > 1.5\ m\,s^{-1}$
5	13:00–16:00	373	368	ESE	$v \leq 1.5\ m\,s^{-1}$
6	13:00–16:00	366	363	E-ENE	$v > 1.5\ m\,s^{-1}$
7	19:00–22:00	368	361	SSE	$v > 1.5\ m\,s^{-1}$
8	19:00–22:00	364	365	E-ENE	$v \leq 1.5\ m\,s^{-1}$
9	04:00–07:00	448	375	WNW	$v \leq 1.5\ m\,s^{-1}$
10	04:00–07:00	427	373	W-WSW	$v \leq 1.5\ m\,s^{-1}$

Table 5
Comparison of the average CO_2 concentration between the CO_2 rural station ($\bar{x}_{\text{"rural"}}$) and the base line CO_2 station ($\bar{x}_{\text{"base line"}}$) maintained by the UBA.

	$\bar{x}_{\text{"rural"}}$	$\bar{x}_{\text{"base line"}}$	in %
Summer	369	370	3.3
Winter	373	369	1.1
$Summer_{day}$	364	363	0.3
$Winter_{day}$	371	367	1.1
$Summer_{night}$	372	378	0.3
$Winter_{night}$	375	371	1.1

7.4. Comparison of types of land utilization

The division of the measurement route into different types of land utilization enables a specified classification of the measurement values to the different kinds of areas. We can differentiate between twelve types of land utilization along the transect, which indicate a high structure of housing (e.g. mixed-use zone, business area), a high rate of emission (e.g. industrial area), and a high percentage of vegetation and open spaces (e.g. forest area, park area). A comparison of concentration of the different types of land utilization, exemplarily for winter, reveals that areas with a high structure of housing or generally with a high rate of emission have a higher concentration than open or green spaces (Fig. 6).

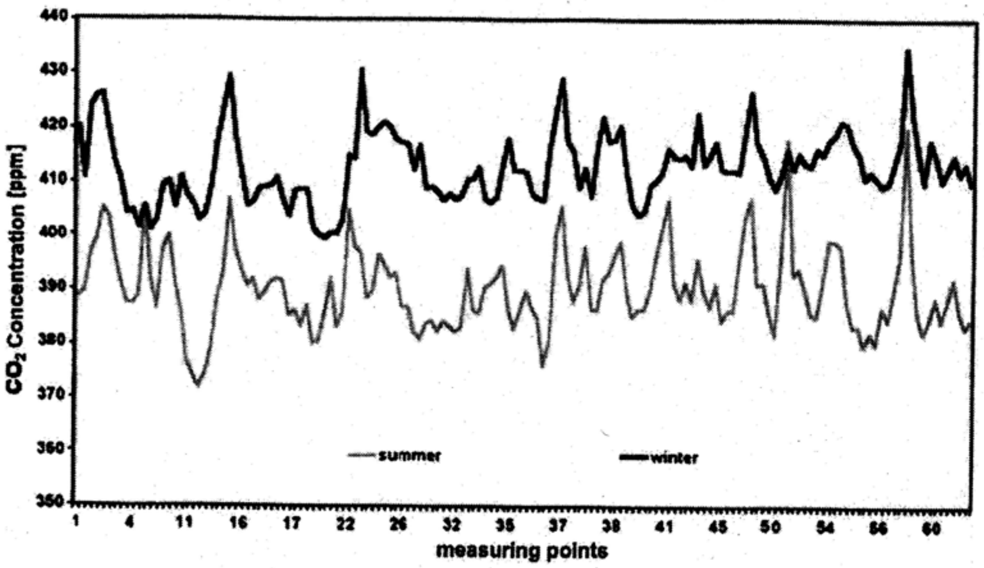

Fig. 4. CO_2 courses through the city of Essen, North Rhine-Westphalia, Germany (winter 2002/2003 and summer 2003; $n = 20$).

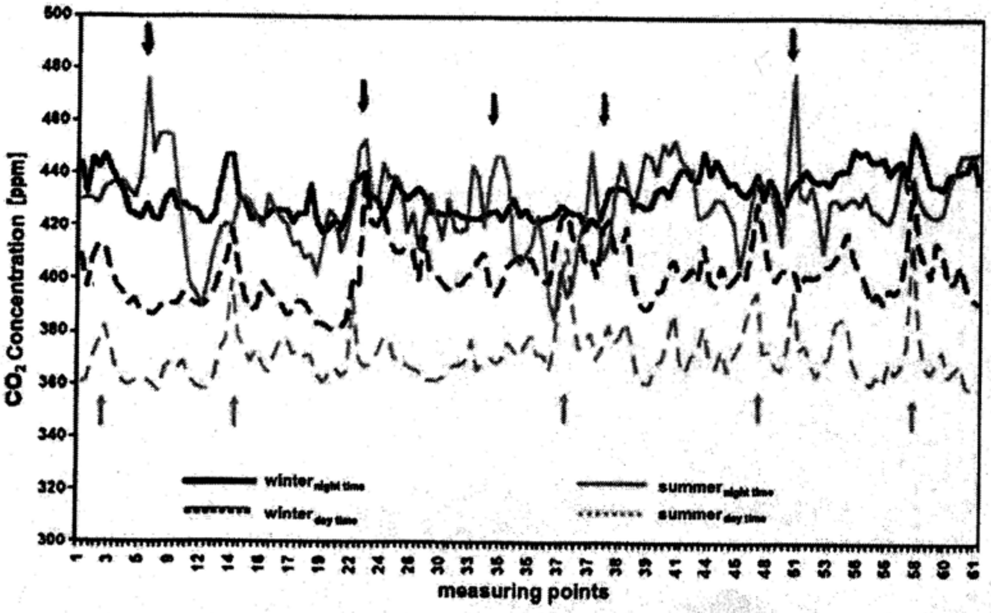

Fig. 5. CO_2 courses through the city of Essen (North-Rhine-Westphalia, Germany), divided into day- (dashed bends) and night-time (solid bends) measurements. Black arrows show up CO_2 peaks during night times, grey ones during daytimes (winter 2002/2003 and summer 2003).

A direct comparison of the CO_2 concentration for the different types of land utilization of winter and summer show up a higher carbon dioxide concentration in winter, independently from the land utilization (Fig. 7).

Indeed, a separate view of daily and nocturnal CO_2 concentration stated a higher concentration for the different types of land utilization during winter days, but not generally for the night time. Land utilizations with a high percentage of vegetation (park area, green spaces, forest area, dump area) indicate a higher CO_2 concentration for summer nights than for winter night times caused by an increasing nocturnal CO_2 plant respiration (Fig. 8).

7.5. CO_2 and other air quality indicators

The influence on carbon dioxide by anthropogenic sources can be reconstructed by calculating the rank correlation coefficients by *Spearman*.

This may give information on how two different air quality components have the same, respectively a similar temporal and spatial pattern along the transect mainly during clear and calm weather situations (Table 6).

Noticeably, the highest coefficients were reached during the day in winter as well as in summer, according to a higher rate of

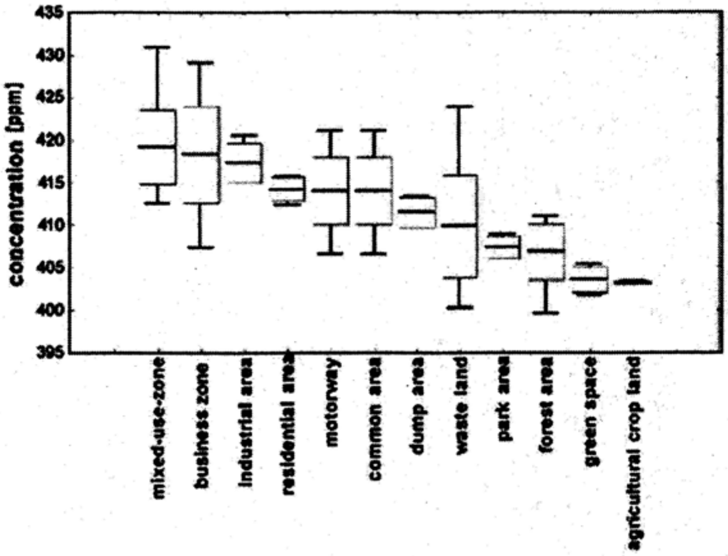

Fig. 6. Box-and-whisker plot for the different types of land utilization in the city of Essen, Germany.

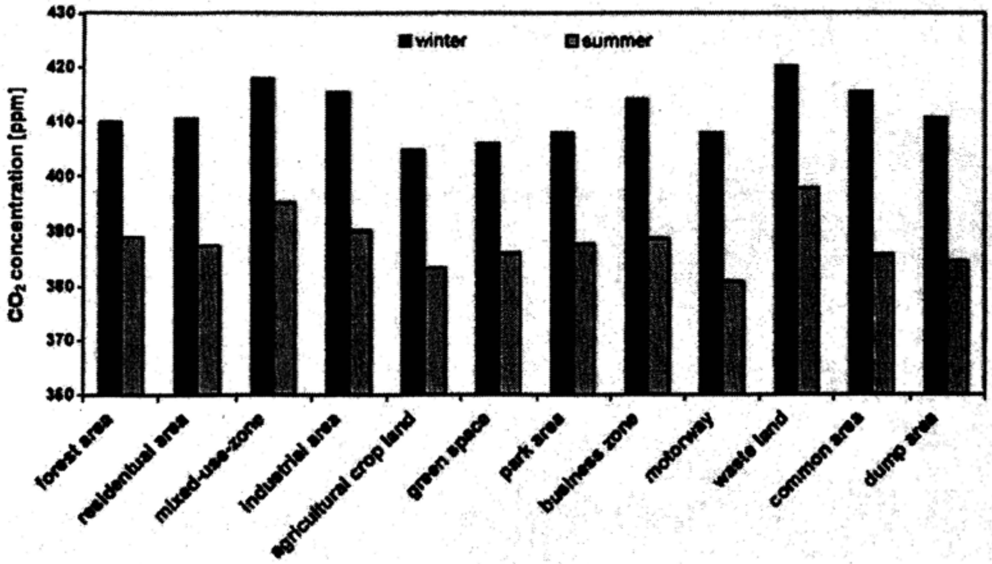

Fig. 7. Average CO_2 concentration dependent on different types of land utilization along the measuring route through the city of Essen, Germany (winter 2002/2003 and summer 2003).

anthropogenic sources, e.g. the CO_2 emission by motor vehicles. At night times, winter coefficients were a little higher than in summer due to more stable atmospheric conditions during cold season nights. This might be indicating an increase of the trace element concentration by domestic fuel, which can generally be measured during winter days and nights.

8. Conclusion

The results of the taken mobile measurements of carbon dioxide in the city of Essen during winter 2002/2003 and summer 2003 have shown that the urban CO_2 mixing ratio can be represented with the help of mobile measurements, which were divided into highly frequented spatial and temporal data. Thus we have the opportunity to show the dependence between the CO_2 concentration of spatially differentiated types of land utilization and the season.

The comparison of the urban and rural CO_2 concentration revealed that the city of Essen does not reach the differences between rural and urban concentration as it is known from other cities (Idso et al., 1998, 2001; Soegaard et al., 2003). The surrounding countryside shows much lower values than the city (wind from S to W) only when the wind has not yet flooded over occupied buildings or builded areas (wind from N to NE).

In contrast to earlier investigations in other cities (Idso et al., 1998, 2001; Nasrallah et al., 2003), significantly seasonal

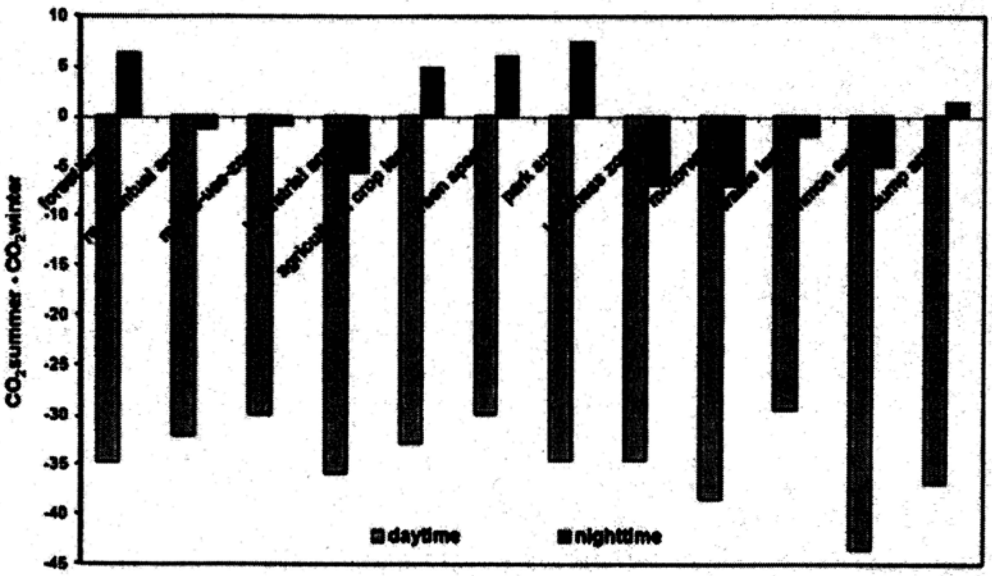

Fig. 8. Difference $\Delta CO_{2\ summer-winter}$ (in ppm) between the prevailing types of land utilization in the city of Essen, Germany, dependent from the time of the day (winter 2002/2003 and summer 2003).

Table 6
Correlation analysis of air quality indicators with CO_2 ($\alpha < 0.05$), divided into day- and night time measurements ($v \leqslant 1.5\ m\ s^{-1}$) for the city of Essen, Germany (winter 2002/2003 and summer 2003).

	CO	NO	NO_2	O_3
$Winter_{day}$	0.739	0.830	0.486	−0.658
$Winter_{night}$	0.393	0.469	0.272	−0.292
$Summer_{day}$	0.628	0.668	0.478	−0.652
$Summer_{night}$	0.256	0.266	0.169	−0.622

differences of the CO_2 mixing ratio ($\bar{x}_{winter} = 415$ ppm unlike $\bar{x}_{summer} = 393$ ppm) could be detected after comparing the summer and winter months. The investigation area can be viewed as an example of a city in the mid latitudes with an observable distinct seasonal change.

Analyzing the average CO_2 concentration of different types of land utilization pointed out that the CO_2 mixing ratio of winter is obviously not generally higher than it is in summer, though suburban and urban areas with a high percentage of vegetation had much higher CO_2 values during summer nights than during winter night times. Due to these results, the CO_2 dome with a steadily rising CO_2 concentration from the rural to the urban area, which is often stated in literature, cannot be confirmed for the city of Essen (Idso et al., 1998, 2001; Clarke-Thorne et al., 2003; Pataki et al., 2003). The higher spatial and temporal frequented CO_2 values indicate an existing significant difference between different urban types of land utilization.

The highly positive diurnal correlation coefficients between CO_2 and other air quality indicators have shown that there is a close interrelation between the primarily measured trace elements (CO, NO). This is due to the higher traffic density along the day, a higher domestic fuel in winter as well as in fact of stable atmospheric condition during the measuring trips.

The results of this investigation have shown how important mobile measurements are for the determination of urban CO_2. That is why it is recommendable to conduct mobile measurements at least for two seasons and with an exact consideration of urban types of land utilization. Otherwise, the seasonal and spatial variations of CO_2 cannot be represented.

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