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Six-year record of atmospheric carbon dioxide and methane at a high-altitude mountain site in Poland

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ABSTRACT

Carbon dioxide and methane observations from the continental mountain station Kasprowy Wierch in the Tatra Mountains, southern Poland, are presented. They cover a six-year period from 1994 to 2000. Significant year-to-year variability of CO_2 concentration was observed. The seasonal cycles 1996–1997 were similar, with a peak-to-peak amplitude of the selected and smoothed CO_2 record of approximately 20 ppm and no significant increase of the annual mean values. For 1998 and 1999 large increases of the annual mean values by 3.3 and 4.0 ppm per year, respectively, were observed. This increase was accompanied by a reduction of the seasonal amplitude of the smoothed record to approximately 15 ppm in 1998 and 16 ppm in 1999. In 2000 the seasonal amplitude increased again to a value similar as in 1996/1997, whereas the mean annual value remained close to that recorded for 1999. Similar features can also be traced in the selected and smoothed CO_2 record for Schauinsland station, Germany, located ca. 1000 km west of Kasprowy Wierch. These similarities strongly suggest that both stations are capturing the same large-scale European phenomena, most probably related to a disturbance of the CO_2 cycle by the recent El Niño event. The mean CH_4 mixing ratio at Kasprowy Wierch for the period 1996–1999 was about 30 ppb higher than over the Atlantic Ocean, confirming previous observations that the European continent is a net source of methane throughout the year. No significant seasonal cycle of methane has been observed at Kasprowy Wierch. The short-term changes of CO_2 and CH_4 are strongly correlated during winter months: the average monthly mean slope of the linear relationship between CH_4 and CO_2 was 10.7 ± 0.3 ppbCH_4 per ppmCO_2. During summer months this strong correlation breaks down. Diurnal changes of CO_2 and CH_4 mixing ratios observed at Kasprowy Wierch are typical for continental mountain sites, with a distinct minimum of CO_2 during afternoon hours in summer and maximum during winter. For CH_4, diurnal cycles have similar shape throughout the year, with a broad maximum during daytime. The mean peak-to-peak amplitudes for summer (July) were 4.5 ppm for CO_2 and 30 ppb for CH_4, whereas during winter (February) they diminished to 1.5 ppm and 10 ppb, respectively.

1. Introduction

Global atmospheric observations of the carbon system are currently focused on providing a means to constrain regional carbon fluxes within an uncertainty of a fraction of a Pg ($=10^{15}$ g) of carbon per year for each region. The current global CO_2 network is heavily biased towards oceanic sites (GLOBALVIEW, 2001). Although in Western Europe the network of observation sites is relatively well developed, a further extension towards Eastern Europe and Asia would be desirable.

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With this aim in sight a new measurement station was launched in September 1994, as a joint project of the University of Mining and Metallurgy, Krakow, Poland, and the University of Heidelberg, Germany. The station is situated on the top of a mountain peak (Kasprowy Wierch) in the Tatra Mountains, southern Poland. It was anticipated that due to its exposed location (19°56′E, 49°14′N; 1987 m a.s.l, ca. 300 m above the tree line) the site would, for at least part of the time, be relatively free of local influences and may provide valuable data on the regional background levels of CO_2.

In this paper we provide the characteristics of the site relevant to regional monitoring of CO_2 and CH_4, and discuss the data available after six years of operation. We assess the usefulness of the site as a potential new station of the European monitoring network of greenhouse gases, extending its coverage towards eastern Europe.

2. Sampling site

The Kasprowy Wierch meteorological observatory is located on a mountain peak in the Tatra Mountains, which occupy the border between Poland and the Slovak Republic (Fig. 1). The mountain is situated at the intersection of three main valleys. The nearest town, Zakopane, is located in the valley, 6 km north of Kasprowy Wierch and around 900 m below the peak.

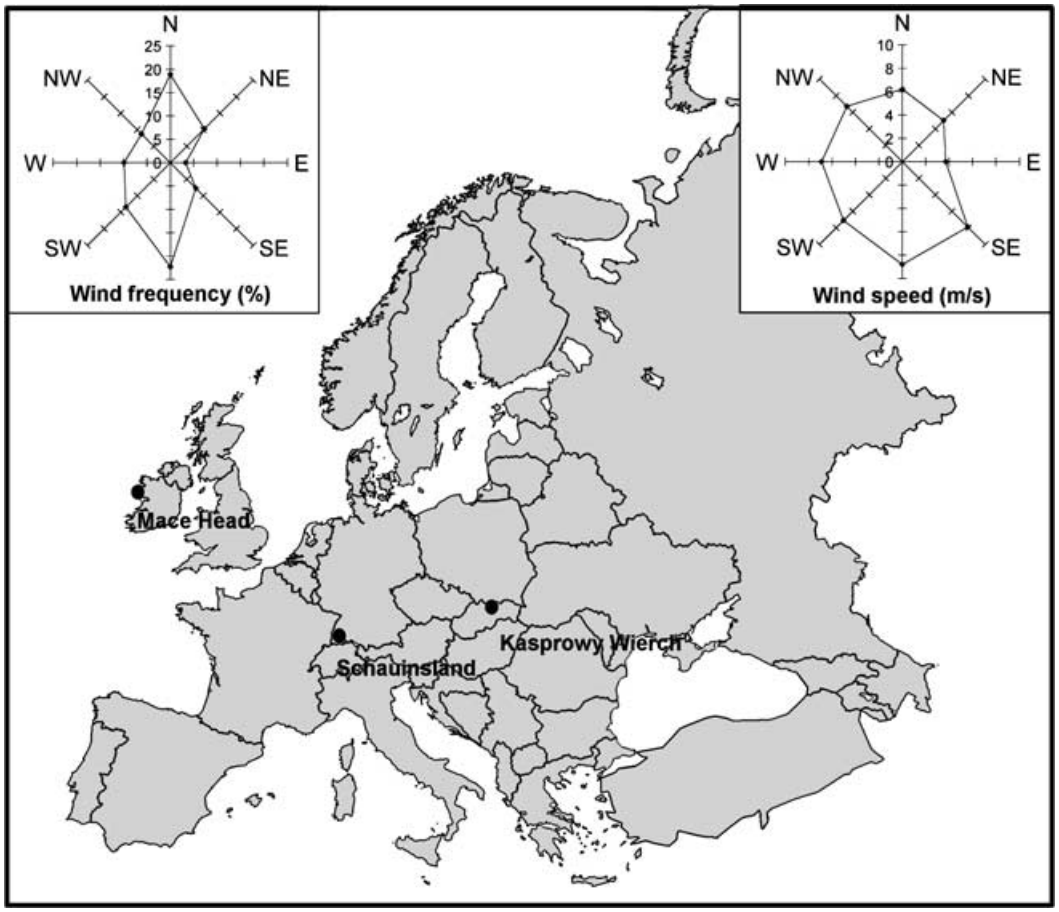

Fig. 1. Map of Europe showing the location of Kasprowy Wierch observatory and other stations discussed in the text. The inserted diagrams show the distribution of wind direction (left-hand diagram) and wind speed (right-hand diagram), recorded at Kasprowy Wierch.

Table 1. *Seasonal and long-term means of basic meteorological parameters for the Kasprowy Wierch observatory (Koncek, 1974)*

Parameter	Month												Long-term annual mean
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Air temperature (°C)	−9	−8	−7	−3	2	5	7	6	5	1	−3	−7	−0.9
Relative humidity (%)	76	76	75	80	85	87	86	86	82	79	77	75	80.3
Precipitation (mm)	104	118	114	115	159	261	235	185	115	116	128	127	1777

This is a small touristic town without industry. During the winter holiday period (January–February) relatively large amounts of wood and fossil fuels are combusted in the valley. The observatory is equipped with an electrical heating system and does not use any fossil fuel. During winter, diesel-operated snow cars are used in the nearby valleys to maintain proper conditions for skiing.

The climate at Kasprowy Wierch station is typical of a continental mountain location, with relatively large diurnal and seasonal variations of temperature, a high precipitation rate, frequent changes of atmospheric pressure and strong winds (cf. Table 1). The winds blow predominantly along a north–south axis, with an average speed of around 7 m s^{-1} (cf. inserts in Fig. 1). The winter season with permament snow cover usually begins in October and lasts typically for 8 months, ending rapidly in June due to strong föhn circulation.

3. Analytical methods

Regular measurements of CO_2 and CH_4 mixing ratios at Kasprowy Wierch observatory started in September 1994. During the first two years, weekly composite air samples were collected in 100 L aluminium-PE bags by continuous pumping at a low flow rate. The intake of outside air was located ca. 1 m above the roof of the observatory and ca. 6 m above the local ground. Duplicate samples in 1 L glass flasks were taken from each bag at the end of each sampling period and analysed for CO_2 and CH_4 content at the Institut für Umweltphysik, University of Heidelberg, Germany (IUP). In addition, between February 1995 and March 1998, duplicate spot samples were collected in 1 L glass flasks every two weeks, always during night hours, close to the inlet of the continuous sampling system. Those samples were analysed also at IUP. In July 1996 a fully automated gas chromatograph (Hewlett Packard, series 5890) was installed in the observatory. A schematic diagram of the analytical set-up is shown in Fig. 2. Basic parameters of the analytical system are summarised in Table 2. The air collected from the same intake as the weekly composite samples is dried prior to analysis with the aid of a commercial drying device (Perma Pure dryer, model MD-125-48) yielding a 10-fold reduction of the partial pressure of water vapour in the analysed air with the adopted flow rate (ca. 130 cm^3 min^{-1}). The data presented below were not corrected for incomplete removal of water vapour from the analysed air by the drying device. The estimated upper limits for the correction of the measured CO_2 mixing ratios due to incomplete removal of water vapour are approximately 0.6 and 0.1 ppm for summer and winter, respectively, assuming 100% relative humidity and respective air temperatures of 10 °C (summer) and −10 °C (winter). For methane these estimated limits are within the analytical reproducibility quoted below.

All CO_2 data are reported on the WMO CO_2 mole fraction scale maintained via secondary standard gases periodically calibrated by IUP. Methane mixing ratios are referenced to standard gases from IUP calibrated by NOAA/CMDL. The reproducibility of the measurements is better than ±0.1 ppm for CO_2 and ±4 ppb for CH_4.

4. Results and discussion

As the Kasprowy Wierch observatory is situated within the transition zone between the free troposphere and the convective boundary layer, one may expect that the "catchment area" for this site will vary seasonally, being generally smaller in summer, when the influence of the mountain breeze becomes important. During winter months, the influence of intense fossil fuel combustion in the nearby town of Zakopane and its surroundings may be visible in the recorded mixing

Table 2. *Basic parameters of the gas chromatographic system*

Parameter of the system	CO_2	CH_4
Detector	FID with Ni catalyst	FID
Column	Porapak Q, 1.5 m	Porapak Q, 1.5 m
Oven temperature (°C)	40	40
Detector temperature (°C)	150	150
Ni catalyst temperature (°C)	375	
Carrier gas flow rate (cm^3 min^{-1})	30	30
Hydrogen flow rate (cm^3 min^{-1})	35	35
Synthetic air flow rate (cm^3 min^{-1})	350	350
Sample flow rate (cm^3 min^{-1})	130	130
Time of analysis (min)	15	15
Reproducibility	0.1 ppm	4 ppb

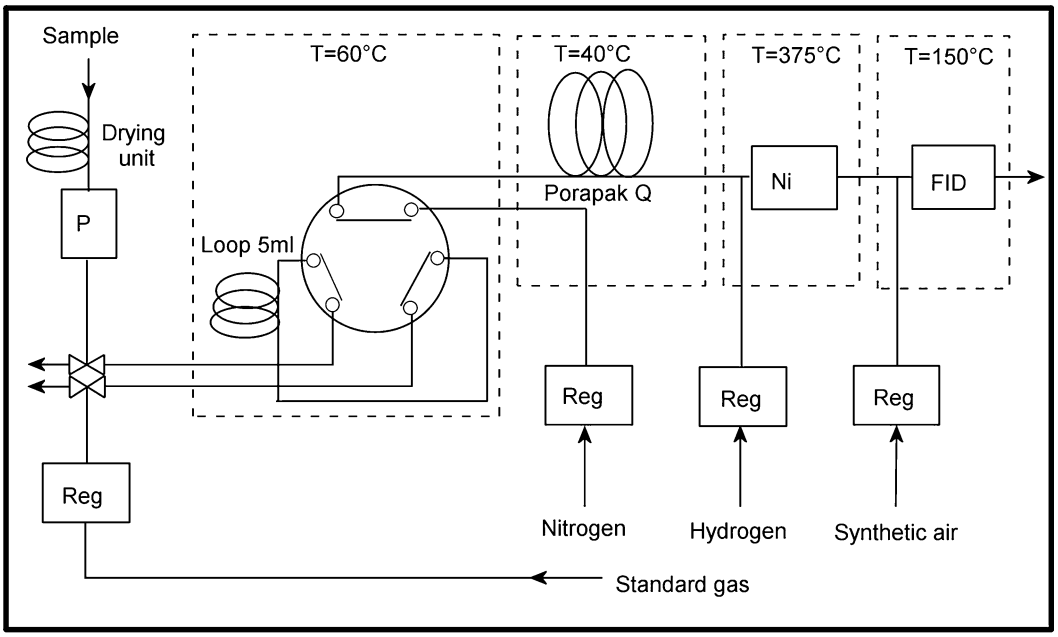

Fig. 2. Functional scheme of the gas chromatographic system to measure atmospheric mixing ratios of CO_2 and CH_4 at the Kasprowy Wierch observatory.

ratios of CO_2 and CH_4. In order to demonstrate true characteristics of the site, both raw and selected data will be presented. Appropriate selection procedures need to be applied when regional background values are of interest.

4.1. Diurnal variability of CO_2 and CH_4 mixing ratios

The typical behaviour of diurnal changes in the CO_2 mixing ratio during summer and winter months is presented in Fig. 3. The figure shows averaged diurnal CO_2 cycles for July 1997 and February 1997, respectively. During summer, photosynthetic activity of the plant cover in the valleys below the observatory gradually reduces the CO_2 content in the surrounding air. When the inversion layer is broken and breeze winds start to transport CO_2-depleted air upslope towards the station, the recorded mixing ratios gradually decrease, reaching a minimum around 3 p.m. In late afternoon, when plant assimilation stops and the inversion layer starts to develop again, the CO_2 mixing

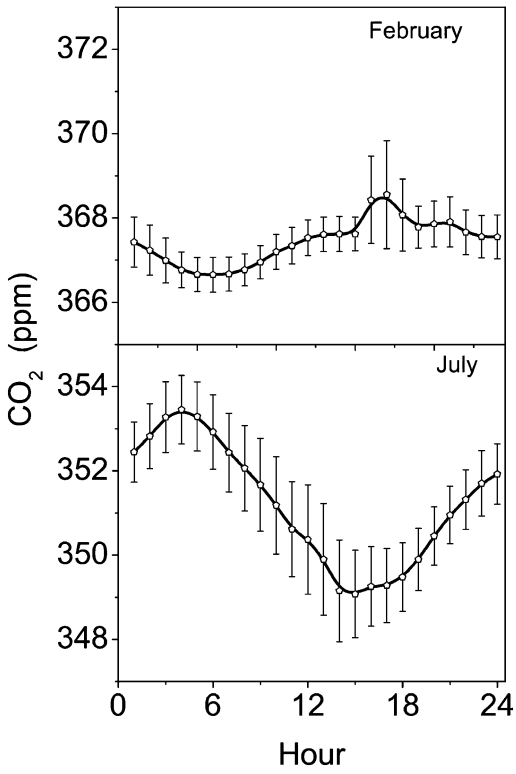

Fig. 3. Mean diurnal cycle of CO_2 mixing ratios measured in February and July 1997 at Kasprowy Wierch station. Error bars indicate one standard deviation ($\pm 1\sigma$) of all available values for the given hour.

ratio rises, reaching a maximum around 4 a.m. The observed peak-to-peak amplitude of the diurnal CO_2 cycle is around 4.5 ppm. Apparent day-to-day variability is largest at mid-day (ca. ± 1.5 ppm, 1σ) and decreases to approximately ± 1 ppm during the night.

The winter season reveals an opposite pattern of diurnal CO_2 changes. After sunrise, the mixing ratio rises gradually as the air loaded with CO_2 from local sources in the valley reaches the observatory. The maximum CO_2 mixing ratio is recorded shortly after sunset. During the night, CO_2 decreases gradually towards background levels, recorded typically during the early morning hours (5–6 a.m.). The mean observed peak-to-peak amplitude of the diurnal CO_2 cycle in winter is of the order of 1.5 ppm. It has to be noted, however, that the observed day-to-day variability in winter, when compared to the amplitude of the respective diurnal cycle, is significantly larger than during summer time. The most probable reason is the proximity and occasional influence of relatively strong anthropogenic CO_2 sources. The largest variability was observed for late afternoon/early evening hours, with a 1σ variability of about 1.5 ppm, which diminished to approximately 0.5 ppm when close to background levels are recorded in the early morning.

The comparison of diurnal CO_2 cycles recorded at Kasprowy station, with the data available for Schauinsland station, Germany (47°55′N, 7°55′E, 1205 m a.s.l.; Schmidt et al., 1996) reveals remarkable differences. The average diurnal cycle for July (1992–1994) at Schauinsland station reaches 8 ppm, i.e. is almost twice as high as recorded at Kasprowy Wierch. This is due to the fact that Schauinsland station is located below the tree line, whereas Kasprowy is located 300 m above the tree line. On the other hand, the diurnal CO_2 cycle at Schauinsland in winter (January 1993–1995) reaches only ca. 1 ppm, a significantly lower value than that recorded at Kasprowy. This in turn confirms the influence of local CO_2 sources at Kasprowy station during winter. Comparison of the mean monthly diurnal CO_2 cycles recorded at Kasprowy during the summer and winter seasons for consecutive years of observation (1997–2000) did not reveal any significant changes in the amplitude of those cycles.

Contrary to CO_2, the overall shape of the diurnal cycle of methane does not change significantly with season, although there are remarkable differences in amplitude (Fig. 4). The maximum CH_4 concentration is observed during late afternoon/early evening hours (6–9 p.m.) and the minimum around 6–7 a.m., when similar background values are recorded during summer and winter. Diurnal CH_4 cycles during summer and winter differ significantly with respect to amplitude: mean CH_4 variation reaches 30 ppb in July and only 10 ppb in February. These differences can be attributed to local emissions of CH_4 by relatively large swamps and peat bog deposits situated ca. 20 km north of Kasprowy station. Also landfills of Podhale region located within the catchment area of Kasprowy Wierch (most of them without adequate gas collection installations) release methane into the atmosphere. These surface sources contribute to elevated CH_4 levels within the boundary layer. They may reach Kasprowy station during daytime, when the inversion layer is destroyed and a mountain breeze operates. Reconnaissance survey of CH_4 emissions carried out in summer 2000 in one of the major wetland areas in the Podhale region revealed fluxes of CH_4 in the order of 60–150 mmol m^{-2} h^{-1} (Necki and Korus, 2001).

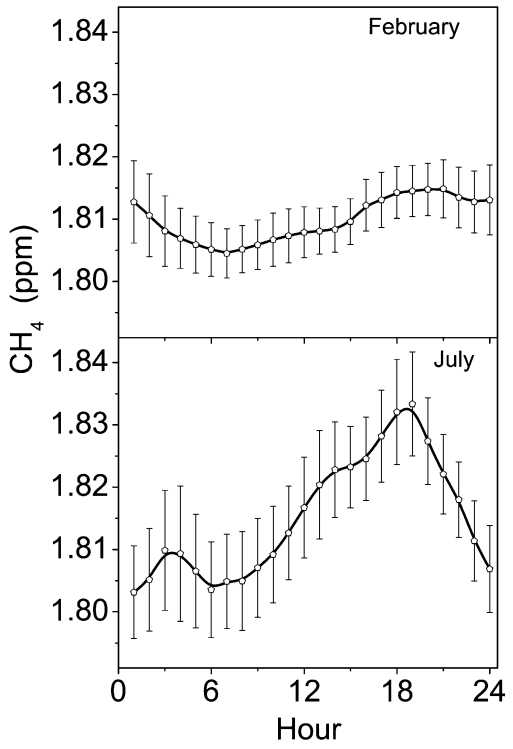

Fig 4. Mean diurnal cycle of CH_4 mixing ratios measured in February and July 1997 at Kasprowy Wierch station. Error bars indicate one standard deviation ($\pm 1\sigma$) of all available values for the given hour.

Comparison with the Schauinsland CH_4 record (Schmidt et al., 1996) reveals comparable peak-to-peak amplitudes of diurnal CH_4 cycles at both stations during winter (ca. 10 ppb) but substantially smaller amplitudes during summer at Schauinsland. The most likely reason for more pronounced diurnal CH_4 cycles at Kasprowy during summer is the proximity of local (natural) methane sources.

4.2. Relationship between short-term changes of CO_2 and CH_4 mixing ratios

Figure 5 illustrates the influence of meteorological conditions on daily changes of CO_2 and CH_4 mixing ratios recorded at Kasprowy station. The first case presented (left-hand panel in Fig. 5) was recorded in March, when biological activity was still largely absent. Passage of a frontal system over the area on March 13 brought air masses loaded with trace gases towards the observatory. Within several hours the mixing ratio of CO_2 increased by about 15 ppm and then returned to background levels. Analogous behaviour was observed for CH_4 (increase by almost 200 ppb) and for sulfur hexafluoride (increase from 4.2 to 5.7 ppt), which was also measured at the station (J. Necki, unpublished data). Backward trajectory analysis performed for this event revealed that the air mass passing Kasprowy Wierch on 13 March stayed over Central and Western Europe for five preceding days. Most probably, this was the time when it acquired those characteristic trace gas signatures, related to the anthropogenic emissions.

The second case presented (right-hand panel in Fig. 5) is also associated with a frontal situation which occurred in July, when the photosynthetic pump operates at full capacity. A drop in atmospheric pressure connected with passage of frontal system on 30 June enhanced the vertical transport of air from the valleys towards the observatory during mid-day and early afternoon hours. The air reaching the observatory was significantly depleted in CO_2, due to intense assimilation by the biota in the valleys, but enriched in CH_4, indicating the presence of surface sources of this gas within the catchment area of the station.

The examples shown in Fig. 5 illustrate the relationship between short-term changes of CO_2 and CH_4 mixing ratios observed at Kasprowy station during different seasons. During winter months, when assimilation by plants is switched off, both gases exhibit similar emission patterns. Variable transport conditions within the boundary layer influence the measured mixing ratios of CO_2 and CH_4 in the same way, leading to a high degree of covariance between both records (Fig. 6). The apparent correlation coefficients (R^2) for winter months are between 0.72 and 0.95, indicating that atmospheric transport patterns within the boundary layer essentially control the short-term variability of CO_2 and CH_4 at this time of year (Fig. 6, left panel). During summer, when an assimilation sink operates during daytime, the correlation between both records is destroyed (Fig. 6, right panel). Table 3 summarises the parameters of linear correlation between CH_4 and CO_2 mixing ratios, calculated for different months of 1997. The mean slope of the linear fit between CH_4 and CO_2, calculated for four winter months (November–February) amounts to 10.7 ± 0.3 ppb CH_4 per ppm CO_2. Comparison with respective data (winter months) for Schauinsland, Germany (around 8 ppb CH_4 per ppm CO_2; Schmidt et al., 1996) and Canadian wetlands (21 ppb CH_4 per ppm CO_2; Conway and Steele, 1989) indicates that, relative to CO_2, emission

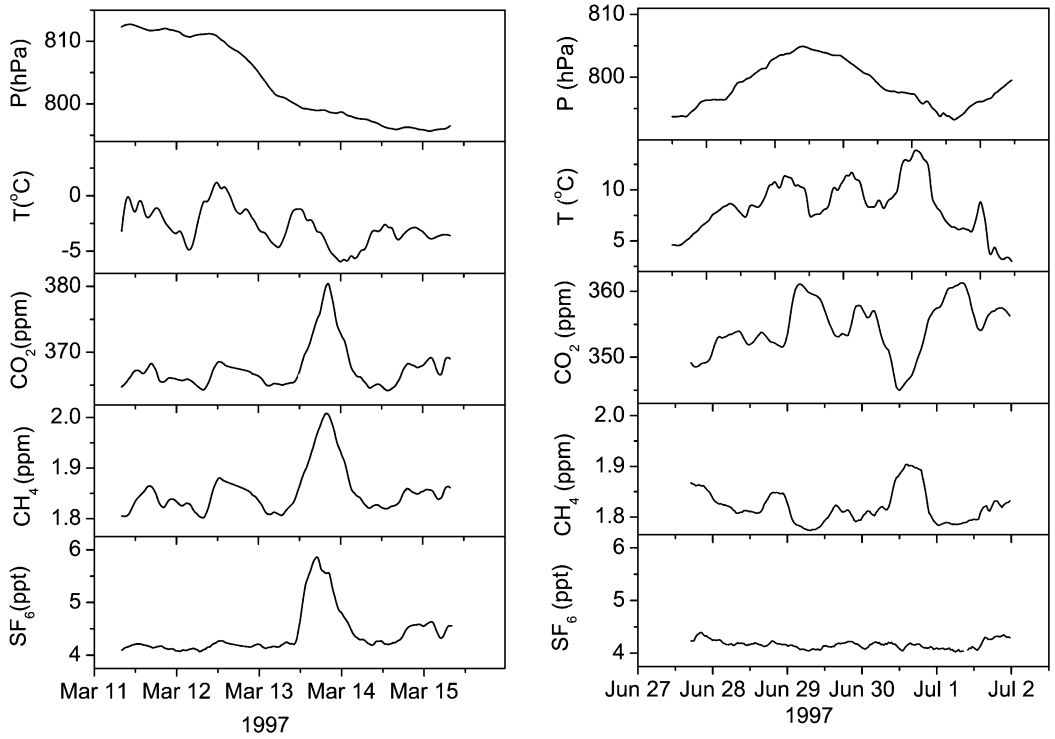

Fig. 5. Examples of the short-term variability of CO_2, CH_4 and SF_6 mixing ratios in relation to meteorological parameters (air temperature, pressure) recorded at Kasprowy Wierch station in March and June 1997.

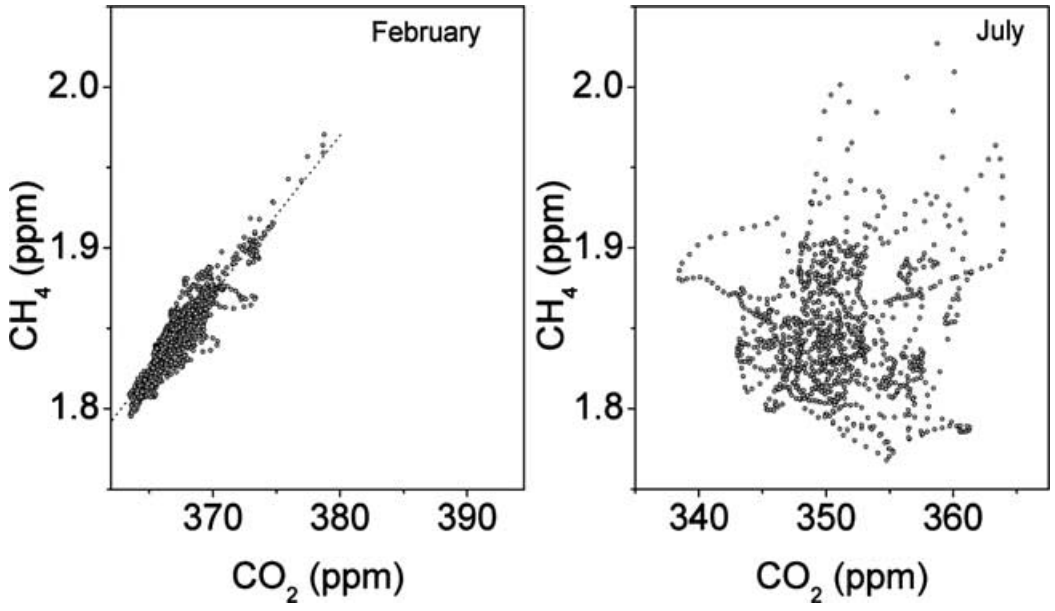

Fig. 6. Correlation between half hourly data for CH_4 and CO_2 mixing ratios, recorded at Kasprowy Wierch station in February and July 1997.

Table 3. *Monthly mean slopes of the regression lines between CH_4 and CO_2 mixing ratios for 1997*

	Slope of the regression line (ppb CH_4 per ppm CO_2)	R^2
January	11.4	0.72
February	9.5	0.80
March	11.0	0.87
April	11.5	0.30
May–October	—	<0.01
November	10.2	0.93
December	11.7	0.95

rates of CH_4 in the catchment area of Kasprowy station are about 20% higher than around Schauinsland station, but much lower than in the Canadian wetlands.

4.3. Seasonal cycles of CO_2 and CH_4 mixing ratios

The record of the CO_2 mixing ratio at Kasprowy station for the period 1994–2000 is shown in Fig. 7. Four types of data are presented: (i) weekly averages based on composite air samples collected in aluminium–PE bags between September 1994 and December 1996 (full squares), (ii) results of measurements performed on spot samples collected between February 1995 and March 1998, every two weeks, always during night hours (stars), (iii) daily mean values based on on-site gas chromatographic measurements, calculated using half-hourly data without any selection procedure (open squares), and (iv) selected daily mean values (open circles). The presented record reveals the typical behaviour of atmospheric CO_2 observed at mid-latitude continental sites of the Northern Hemisphere. The winter maximum ends in March, when the photosynthetic sink starts to operate. From that time on, the CO_2 mixing ratio gradually decreases, reaching a minimum in August/September. Afterwards, the CO_2 level rises, reaching maximum values in January–February.

The selected and smoothed data for the portion of the record obtained through on-site gas chromatographic measurements is presented in the lower panel

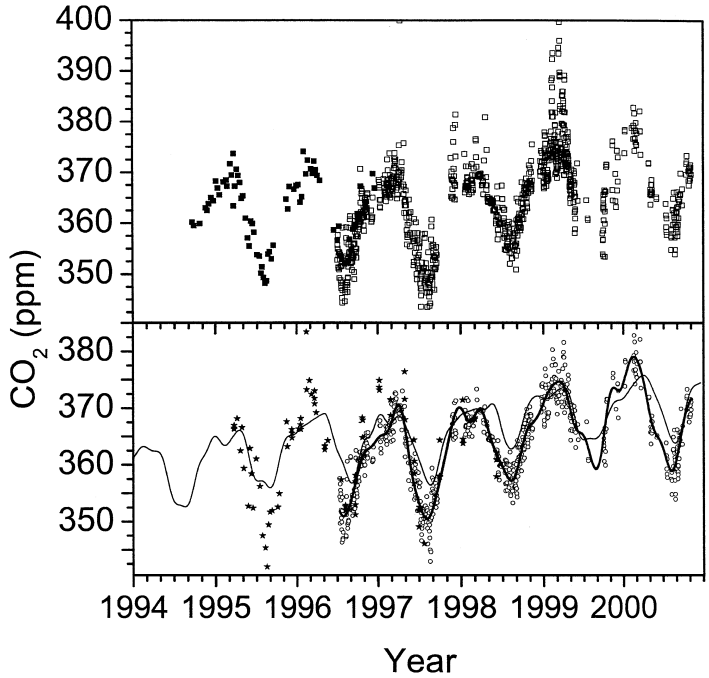

Fig. 7. Record of CO_2 mixing ratios available for Kasprowy Wierch station. Upper panel: average weekly data obtained from composite air samples (full squares) and daily mean data, calculated on the basis of half hourly gas chromatographic measurements, without any selection procedure (open squares). Lower panel: selected and smoothed data for the part of the record obtained through on-site gas chromatographic measurements (open circles and heavy line). The thin line shows the harmonic fit curve through the selected CO_2 data for Schauinsland station, Germany. The data derived from spot air samples collected between February 1995 and March 1998 at Kasprowy Wierch station are also shown for comparison (stars).

of Fig. 7 (heavy line). The data selection procedure consisted of three steps: (i) only night-time values (22 p.m.−6 a.m.) were considered, (ii) the mean value for the given night was accepted only if it did not deviate from the average of the accepted mean values calculated for seven preceding nights by more than 3 standard deviations. However, (iii) the mean value for the given night was rejected if the calculated standard deviation for the set of half-hourly data available for that night was larger than 2 times standard deviation calculated for the entire population of the respective standard deviations derived on the basis of the values accepted in steps (i) and (ii). Whereas step (ii) should remove events of anomalously high (low) CO_2 levels lasting at least several hours, the role of step (iii) is to filter out periods of high-frequency variations. Attempts to include the wind speed observations in the selection criteria did not provide meaningful results (Necki, 1998). The selected data are shown in the lower panel of Fig. 7 as open circles. They were further smoothed using the routine recommended by NOAA/CMDL (CCGvu, version 4.40; www.cmdl.noaa.gov/ccgg/resources/sw/ccgvu). The lower panel of Fig. 7 also contains the selected and smoothed CO_2 record for Schauinsland station, Germany, for the period 1994–2000 (thin line). The smoothing was performed using the same NOAA/CMDL routine, with identical settings. For comparison, in the lower panel of Fig. 7 the results from the night-time spot samples for 1995–1998 are also shown. One should, however, keep in mind that the night-time spot samples may still contain a significant component related to local sources of CO_2.

Although the record presented from Kasprowy Wierch station is still too short to meaningfully address the question of long-term changes, significant year-to-year variability of the CO_2 mixing ratio is apparent from Fig. 7. The seasonal cycles 1996–1997 were similar, with a peak-to-peak amplitude of the smoothed record reaching approximately 20 ppm and no significant increase of the annual mean values. For 1998 and 1999, large increases of the annual mean values by 3.3 and 4.0 ppm per year, respectively, were observed. This increase was accompanied by a reduction of the seasonal amplitude of the smoothed record to approximately 15 ppm in 1998 and 16 ppm in 1999. In 2000 the seasonal amplitude increased again to a value similar as in 1996/1997, whereas the mean annual value remained close to that recorded for 1999 (368.9 ppm). Interestingly, similar features can also be traced in the selected and smoothed CO_2 record for Schauinsland station, although the amplitudes recorded there are generally smaller. They changed from approximately 15 ppm in 1996 and 1997 to 8–10 ppm in 1998 and 1999. In 2000 also at Schauinsland station, the seasonal amplitude returned to the values observed in 1996 and 1997. These similarities strongly suggest that both stations are capturing the same large-scale European phenomena, most probably related to disturbance of the CO_2 cycle by the recent El Niño event.

The available record of CH_4 mixing ratio at Kasprowy Wierch is presented in Fig. 8. The upper panel of Fig. 8 shows daily mean values based on on-site gas chromatographic measurements, calculated using half hourly data without any selection procedure (open squares) and weekly averages based on composite air samples collected between September 1994 and December 1996 (full squares). The open circles in the lower panel of Fig. 8 represent selected data. The selection procedure was analogous to that used for selection of CO_2 data. For comparison, also spot night-time flask data are shown in the lower panel of Fig. 8 (stars).

The lower panel of Fig. 8 also contains four curves representing monthly mean CH_4 mixing ratios for: (a) Mace Head station, Ireland (53°20′N, 9°54′W, 25 m a.s.l.; NOAA/CMDL, 2001), (b) Schauinsland station (selected data), (c) Kasprowy Wierch station (gas-chromatographic data, selected), and (d) Kasprowy Wierch station (composite samples).

To a first approximation, the CH_4 record of Mace Head can be considered as a marine background reference for the European continent, in the latitude band around 50°N. It is apparent from Fig. 8 that the weak seasonal cycle present in the Mace Head record disappears over the continent. The seasonality of CH_4 concentration in a clean, marine environment is linked to the reaction of methane with OH radicals, which depends on the seasonally varying intensity of UV radiation (Fung et al., 1991; Steele et al., 1992). Over Europe, this weak seasonal signal is overshadowed by relatively strong, mainly anthropogenic emissions of CH_4, related to ruminants, leakages from natural gas supply, coal mining and waste deposits, which are not likely to vary significantly with season (Thom et al., 1993).

The mean offset between monthly means of selected CH_4 data for the Kasprowy Wierch and Mace Head stations for the period 1996–1999 amounts to 24 ± 4 ppb (1σ of the mean value). For the Schauinsland station the analogous offset is equal 13 ± 2 ppb. If, instead of the Mace Head data, a composite marine background

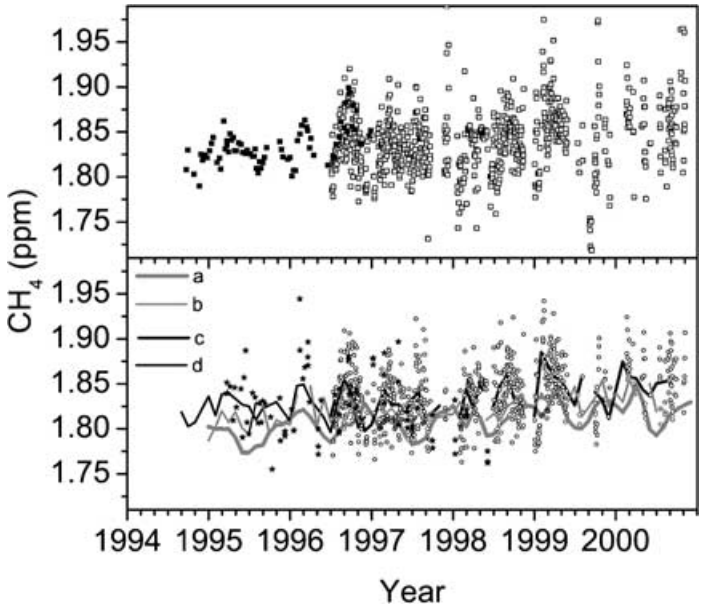

Fig. 8. Record of CH_4 mixing ratios available for Kasprowy Wierch station. Upper panel: average weekly data obtained from composite air samples (full squares) and daily mean data, calculated on the basis of half hourly gas chromatographic measurements, without any selection procedure (open squares). Lower panel: selected data for the part of the record obtained through on-site gas chromatographic measurements (open circles) and the measurements performed on spot air samples collected every two weeks, always during night hours (full stars). The lines represent monthly mean CH_4 mixing ratios for: (a) Mace Head station, Ireland (selected data); (b) Schauinsland station, Germany (selected data); (c) Kasprowy Wierch station (gas-chromatographic data, selected); (d) Kasprowy Wierch station (weekly composite air samples).

curve is adopted (the weighed mean of Mace Head and Izaña stations: 4 times Mace Head, one times Izaña; Schmidt, 1999), the mean offset increases to approximately 32 and 21 ppb for Kasprowy Wierch and Schauinsland stations, respectively. The larger mean offset recorded at Kasprowy Wierch might be an indication of a gradual loading of the lower atmosphere over Europe with methane of anthropogenic origin when one moves from the Atlantic coast towards the interior of the continent.

Although the records of monthly means of CH_4 available for Schauinsland and Kasprowy Wierch do not reveal any significant seasonality, they do show numerous minima and maxima in the CH_4 mixing ratio of variable extent and magnitude. Some of them can be clearly identified in both records, such as the relatively large maxima in February and in August–September 1996, or smaller maxima and minima in 1997. The most prominent and extensive maximum of CH_4 was recorded at Kasprowy station in 1999, when in February–March the mixing ratio of methane was approximately 60 ppb higher than at Mace Head. During these two months, anomalously high daily mean mixing ratios of CO_2 were also frequently recorded.

The Kasprowy record also reveals two distinct minima (December 1996 and 1999) when the apparent CH_4 level at Kasprowy Wierch was slightly lower than at Mace Head. It remains to be demonstrated to what extent the observed variability of the CH_4 record at Kasprowy station, superimposed on the long-term trend, can be linked to varying circulation patterns of the atmosphere over Europe and eventual changes in the source distribution and strength of this gas on the continent.

5. Concluding remarks

The Kasprowy Wierch observatory belongs to the same category of stations as Schauinsland station in Germany (Schmidt et al., 1996) and Mt. Cimone station in Italy (Cundari et al., 1995). They are all mountain sites, situated within the transition zone

between the free troposphere and the convective boundary layer. During wintertime such sites are often above the boundary layer inversion and may provide reliable information on free tropospheric levels of CO_2 and CH_4. During summer, local sources and sinks of these gases associated with biospheric activity and/or anthropogenic emissions may substantially influence the recorded trace gas concentrations. Objective data selection criteria to filter out such influences in this case are much more difficult to define, compared to coastal sites or very high altitude sites. Nevertheless, such sites play an important role in defining regional background levels for trace gas concentrations over continents.

The data accumulated during six years of operation of the Kasprowy Wierch station allowed us to quantify the characteristics of this station as a potential monitoring site for carbon dioxide and methane. The results obtained to date show that, although the site is not free of local influences, it may still provide meaningful information on the short- and long-term variability of those gases in the atmosphere over Eastern Europe. In particular, the comparison of selected and smoothed CO_2 data for Kasprowy Wierch and Schauinsland stations for the period 1996–2000 revealed that both stations are capturing the same continental phenomena, most probably related to disturbance of the CO_2 cycle by the recent 1998–1999 El Niño event.

The position of Kasprowy Wierch station on the eastern border of the highly populated and industrialised region of Western and Central europe is particularly attractive as a preferred monitoring site for methane concentrations in the lower troposphere. With the prevailing westerly circulation over western and central Europe, the air masses moving eastward are accumulating CH_4 from distributed surface sources, mostly related to anthropogenic activity. The observed gradual build-up of CH_4 concentration over the European continent with increasing distance from the Atlantic coast can be used as an indicator of integrated source strength of methane emissions across Europe.

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