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Carbon dioxide concentration measurements at a rural site in Hungary

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ABSTRACT

At K-puszta, Hungary, the atmospheric concentration of carbon dioxide has been measured since 1981 as part of the WMO BAPMoN program. The time-series is self-consistent, even though the data have not been corrected for the carrier-gas effect. Assuming a linear trend, the rate of increase of the concentration is 1.82 ppm/year. The paper presents the strong daily and seasonal variations which are caused mainly by the vegetation. The temporal course of the growth rate shows similarities with those observed at the NOAA baseline stations, although the seasonal cycle is a few weeks ahead of those of Mauna Loa and Point Barrow.

1. Introduction

The atmospheric concentration of carbon dioxide has been steadily increasing for at least 200 years due to human activity. This increase threatens us with the enhancement of the greenhouse effect of the atmosphere which may lead to global climatic change. A better understanding of the global carbon cycle is crucial for the prediction of the future CO_2 concentration levels. In the recent years, several papers based on atmospheric CO_2 data and model calculations (Keeling et al., 1989; Tans et al., 1989, Tans et al., 1990, Enting and Mansbridge, 1991) concluded that the atmospheric CO_2 data suggest a significant CO_2 sink in the northern hemisphere. As the nature of that sink and its strength are not yet known with certainty, the measurements carried out on the continents of the northern hemisphere have received increased attention. In this paper, we present the CO_2 concentration measurements carried out at the K-puszta WMO GAW station, located in central Europe.

2. Sampling site, characteristics of the data

K-puszta is located at 46°58′N, 19°33′E, 125 masl, on the Hungarian Great Plain, in the middle of the Carpathian Basin (Fig. 1). The station is located in a clearing in a mixed forest (tree height 8–12 m) in which the dominant species is Scotch fir. K-puszta is as free from direct pollution as it is possible in the highly industrialized, densely populated central-Europe. The biggest pollution source in this region is Budapest (2 million inhabitants), approximately 80 km NNW from K-puszta. The nearest bigger city is Kecskemét (100 thousand inhabitants), located 20 km from the station in SSE direction. The prevailing wind in this region is north-westerly. At K-puszta, the Institute for Atmospheric Physics of the Hungarian Meteorological Service has been operating a SIEMENS ULTRAMAT 3 CO_2 analyzer since July, 1981. The air inlet of the instrument is at 10 m above the ground. The instrument was regularly calibrated against CO_2-in-nitrogen standards obtained from the Scripps Institution of Oceanography. Köhler's method (Köhler, 1974) is used to avoid the water vapour influence: the air to be analyzed is saturated with water vapour at room temperature then cooled down to +4°C. This way, the water vapour content of the air to be analyzed is kept constant (saturated at +4°C). The data presented in this paper are expressed on the 1974 WMO Manometric Scale and are not yet corrected for the carrier-gas effect (Griffith, 1982).

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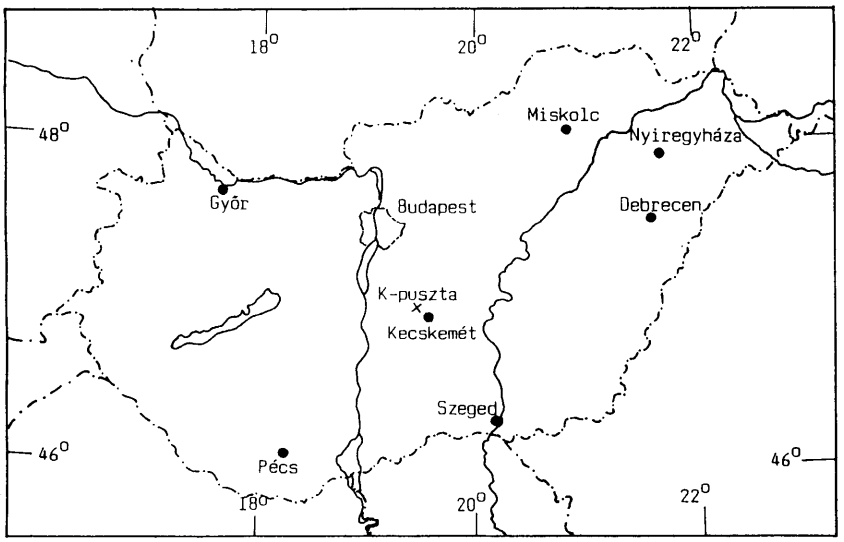

Fig. 1. Location of K-puszta and the main cities (more than 100,000 inhabitants) around it.

(Preliminary results show that the data are approximately 2.5 ppm low, fairly evenly over the entire measuring range.)

The raw data from the station are the 30-min average concentration values. For data selection, the commonly used clean air sector method (sector from which no anthropogenic influence is expected) cannot be used for several reasons: (1) the region is climatologically characterized by low wind speed, typically below 5 m/s, and the surrounding forest may influence the air flow pattern; (2) the strong effect of the vegetation around the measuring site may hide the small differences in the carbon dioxide concentration of air masses coming from different directions, especially in calm weather; (3) every year, there are a few periods, predominantly in winter, in which a very stable boundary layer forms in the Carpathian Basin with limited vertical mixing which leads to the accumulation of gases (mainly of anthropogenic origin) emitted on the surface, i.e., carbon dioxide. That is why only the instrumentally false data are omitted from the database. As illustrations to the phenomena mentioned above, Fig. 2 shows the effect of the vegetation on a calm summer night, when the air coming from different directions from the depth of the nearby forest causes high fluctuations in the average concentration, which is also high in the stable night-time boundary layer. In Fig. 3 the accumulation process, mentioned as argument (3), can be observed, when the concentration goes higher and higher every day.

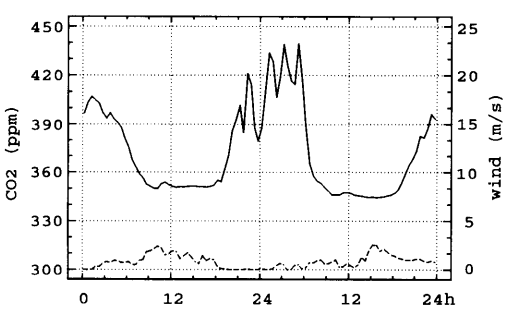

Fig. 2. Wind speed and carbon dioxide concentration on 12–13 June 1991.

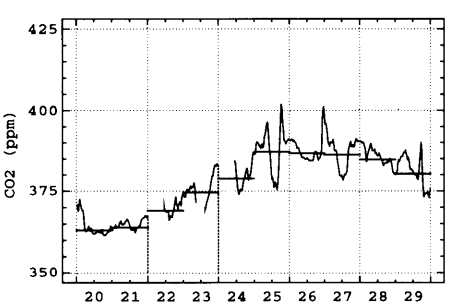

Fig. 3. Accumulation of CO_2 during 20–29 January 1992. The horizontal lines indicate the daily averages.

3. Daily variation and the effect of the meteorological conditions

As can be seen in Fig. 2, the photosynthesis and respiration of the vegetation result in a pronounced daily concentration variation. The CO_2 release and absorption by the plants and by the soil depend on the season, on the photosynthetically active insolation, while the actual concentration formed in the surface layer is also influenced by the stability of the atmosphere. To study the effects of the insolation, mixing and season on the daily variation of CO_2 concentration, the detrended concentration data for 1990–1992 have been sorted into 8 classes formed by the combination of summer/winter, calm/windy, cloudy/sunny. This period was chosen because solar radiation measurements were started at K-puszta only in 1990. The concentration data were detrended for 1 July 1991, calculating a linear trend of 1.67 ppm/year for 1990–1992. Winter was defined as December–February, while the summer period in our calculation is June–August. A day was considered sunny if the total daily global solar radiation exceeded 1600 J/cm^2 in summer and 550 J/cm^2 in winter, respectively. A day was considered cloudy if the total daily global solar radiation remained below the above limit and the hourly global solar radiation did not exceed 250 J/cm^2 and 100 J/cm^2, respectively, even at the brightest hour of the day.

The windy/calm classification was made hour by hour. An hour was defined as windy if the hourly average wind speed was higher than 1 m/s. A higher limit would have been desirable, but K-puszta is located in a climatologically calm region and with a higher limit, we could not find enough windy hours for the study of the CO_2 daily variation. The number of hourly averages available for the compilation of the average daily variation for a certain category is summarized in Table 1.

Fig. 4 shows the spectacular daily variation in CO_2 concentration in summer under different meteorological conditions. The night-time concentrations in calm weather exceed the concentrations observed on windy nights by 30–40 ppm; this is the result of the accumulation of CO_2 respired by the plants and the soil into the stable boundary layer. The night-time respiration of the vegetation may depend on the photosynthesis in the preceding hours: after a sunny day, the night-time concentrations are higher than after a cloudy day in both calm and windy nights. However, during clear nights which are likely to follow sunny days, the surface cooling is more efficient and stronger/shallower inversions can be expected. This process may lead to the same effect in the nocturnal CO_2 concentration. The separation of the effects of the above processes needs further studies.

Table 1. *Number of hourly averages available for the calculation of the typical daily concentration variation under different meteorological conditions; the number of data varies hour by hour in the given range*

		Winter	Summer
cloudy	calm	33–53	7–20
	windy	32–52	5–15
sunny	calm	8–33	17–45
	windy	12–37	6–34

On a calm sunny day, the photosynthesis quickly decreases the carbon dioxide concentration in the stable surface layer right after sunrise. It is a much slower process on cloudy days. However, in both cases, the increasing vertical mixing also leads to decrease in the concentration. Obviously, the lowest concentrations are measured on calm sunny days (intensive photosynthesis and low vertical mixing). The highest day-time concentrations occur during calm, cloudy weather when the vertical mixing is low and the CO_2 content accumulated during the night in the boundary layer is not drawn down by intensive photo-

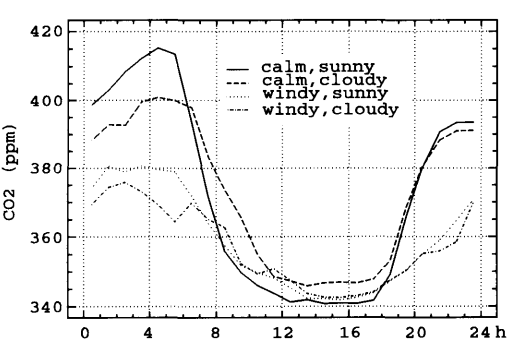

Fig. 4. Diurnal variation of CO_2 concentration in summer under different meteorological conditions.

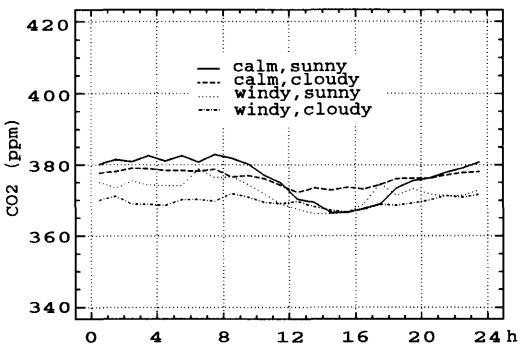

Fig. 5. Diurnal variation of CO_2 concentration in winter under different meteorological conditions.

synthesis. However, the differences among the early afternoon concentrations are small, in some cases statistically non-significant.

For the daily average concentration, the wind, characterizing also the vertical mixing, is the determining factor. In calm summer weather, the daily average concentration of CO_2 is 374.1 ppm if the sky is cloudy, while 372.2 ppm on a sunny day. The higher concentrations in the night are compensated by the lower daytime values. The average daily amplitude on sunny days is as high as 75 ppm. On a windy day, the daily average concentration is approximately 15 ppm lower, and the difference between the sunny and cloudy days is similar to that on the calm days.

The basic characteristics of the daily variation are very similar in winter; however, the daily amplitudes are much smaller (Fig. 5). Although the fir dominant in this region may absorb carbon dioxide even in this season of the year, the observed daily variation is likely to be caused by the anthropogenic emission and the daily variation of the stability of the boundary layer. The mean daily average concentrations vary between 369 ppm (windy, cloudy) and 377 ppm (calm, sunny), which are 14–22 ppm above the background concentration observed at Mauna Loa. This surplus is caused partly by the vegetation and partly by human activity (for the Hungarian CO_2 budget see Mészáros and Molnár, 1992).

4. Trend and seasonal variation

Due to the strong influence of the weather on the carbon dioxide concentration through the vegetation and atmospheric stability, as was presented in the previous section, the day-to-day changes in the daily average concentrations can be as high as 20–25 ppm. Therefore, for the calculation of the trend and seasonal variation, the monthly averages are used. The monthly averages are calculated from the daily averages if at least 10 daily averages are available for the month. The daily averages are calculated only in those cases

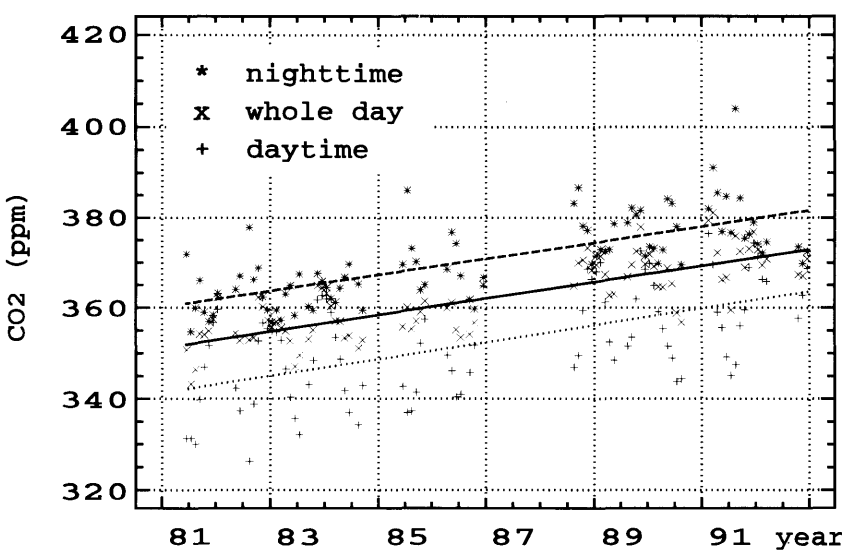

Fig. 6. Trends of the daytime, whole day and night-time concentration values at K-puszta.

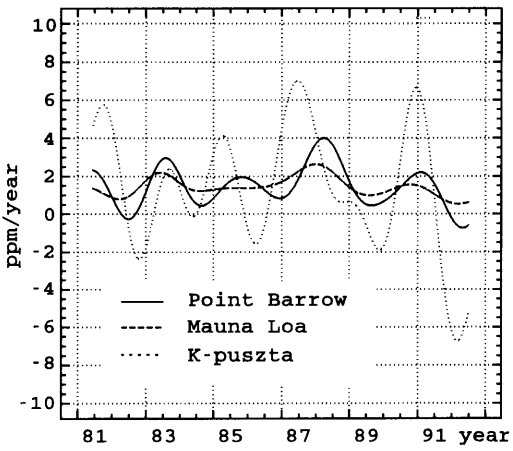

Fig. 7. The time-dependent trend of the CO_2 concentration values measured at K-puszta.

where daytime and night-time periods (defined according to the season) are equally represented. Otherwise, the significant daily variation (see previous section) would distort the daily average. In this way, 87 monthly averages can be determined for the period from July 1981 to December 1992. This means that monthly data are available for 63% of the total measuring period. Most of the missing data are due to instrument malfunctioning. The linear trend is 1.82 ppm/year which is comparable with the trends observed at other measuring sites (Ciattaglia et al., 1987; Levin et al., 1990; Gaudry et al., 1990; Gaudry et al., 1991; Nakazawa et al., 1991), although this is in the higher part of the observed range. This comparison is valid, since the carrier-gas effect, which has not yet been corrected for in this data set, is found to be approximately constant through the measurement period. To filter out the potential effect of the growing local vegetation, we have repeated the trend calculations for the monthly averages including only the night-time values and only the daytime concentration values separately. The results do not differ significantly (1.86 ppm/year for the daytime values and 1.80 ppm/year for the night-time values, see Fig. 6).

From the trend calculation presented in Section 3, it became apparent that the rate of increase is different for different time periods. Approximation with a 2nd-order polynomial ($y = 350.883 + 2.176x - 0.039x^2$, where x is expressed in years and $x = 0$ on 1 January 1981) supports the guess that the growth rate has decreased during the years. The trend calculations have also been repeated using a more sophisticated method (Thoning et al., 1989) which also gives information on the temporal course of the growth rate (Fig. 7). Although (because of the large gaps in K-puszta data series) the result may be rather qualitative than quan-

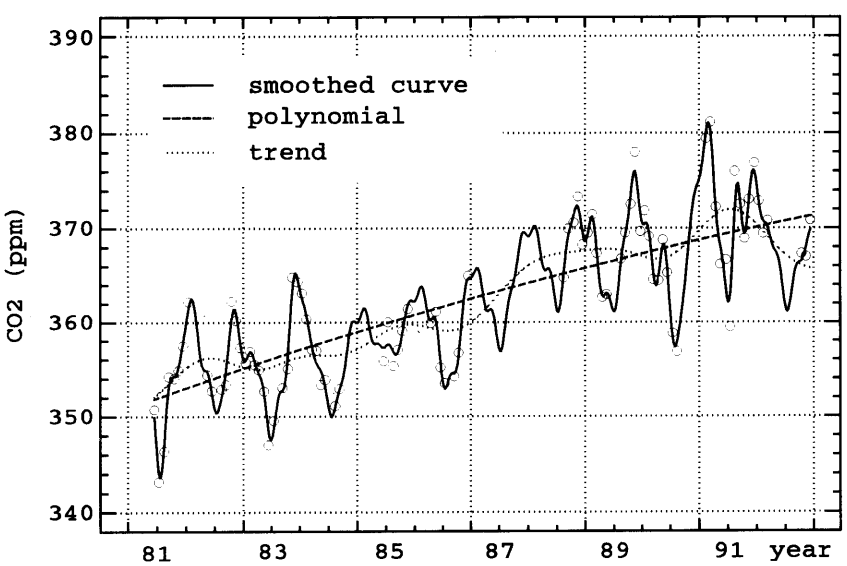

Fig. 8. The annual growth rate at Point Barrow, Mauna Loa (data courtesy of NOAA CMDL) and K-puszta.

titative, there are similarities between this curve and those for some northern hemispheric baseline stations also presented in Fig. 8. The growth rate increased at each station in 1983, 1985, 1987, 1990/1991, but decreased in 1982, 1984, 1986, 1989 and 1992.

The data show pronounced seasonal variations (Fig. 7). The CO_2 surplus season lasts from early/late October to late March/mid-April at K-puszta. The amplitude of the annual cycle varies between 8–22 ppm, but no significant trend can be observed in the amplitude (Kohlmaier et al., 1989; Thoning et al., 1989). The minimum concentration is reached in July, while the maximum is smoother in the winter months. The minimum at K-puszta is ahead of Mauna Loa by 11 weeks, and ahead of Point Barrow by 6 weeks. This confirms that the seasonal cycles observed at Mauna Loa and Point Barrow are generated by ecosystems on the continents in the temperate zone. The further away a measuring site is from the source area, the more attenuated and delayed in phase the seasonal cycle becomes. This phenomenon is also supported by the results of the new NOAA flask sampling sites in China and Mongolia (P. Tans, personal communication, NOAA Carbon Cycle Group).

5. Acknowledgement

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