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CO_2 transport by urban plumes in the upper Spanish plateau

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ABSTRACT

CO_2 transport from two cities, Valladolid, over 20 km away and Palencia, over 40 km away from a rural site is analysed through three years of detrended CO_2 concentrations obtained near the surface. Meteorological data were obtained from a RASS sodar. Directional analysis by histogram of concentrations above the 95th percentile revealed three differing sectors, one associated to a rural origin and two linked to both cities. Modes indicated anticyclonic turning during plume travel, confirmed by the daily evolution of the wind direction. At night, the Valladolid concentration median was 6 ppm above the Palencia median, which was 2 ppm higher than the rural sector median. Monthly evolution of daily maxima evidenced the Valladolid plume influence in spring and September, whereas the Palencia plume was noticeable in October and November. Skewness analysis showed almost symmetric distributions in the Valladolid plume and right skewed distributions in the Palencia and rural sectors. This result was attributed to the different mixing of both plumes. Vertical gradients of wind speed, direction and potential temperature were also calculated, and evidenced a stratified structure of the lower atmosphere at night and an almost uniform layer during the day. Finally, the median gradient Richardson number showed the highest values, occasionally above 0.8 for the Valladolid sector, implying lower mixing with the environment in the Valladolid plume than in the Palencia plume.

1. Introduction

High CO_2 concentrations recorded at rural sites are critical in the life cycle of plants, since the timing of flowering is sensitive to this greenhouse gas (Springer and Ward, 2007). These high concentrations are the result of several factors such as sources and meteorological variables. In this sense, concentrations significantly increase during the night under stable stratification (Moriwaki et al., 2006). However, near-surface air temperature has little impact (Idso et al., 1999). Other factors are climatic conditions such as the warming effect on heterotrophic respiration (Kaufmann, 2007) and even the El Niño Southern Oscillation (Chamard et al., 2003).

CO_2 has been measured in urban environments, which are the major sources (Pataki et al., 2003; Henninger and Kuttler, 2007; Lai and Cheng, 2009). Directional analyses have also been performed to explore the impact of rural air masses on the urban environment (Idso et al., 2001; Nasrallah et al., 2003). Moreover, a comparison between urban and rural CO_2 concentrations has occasionally been considered (Idso et al., 2002; George et al., 2007). However, analyzing the impact of CO_2 urban plumes on rural environments is uncommon. It is known that in the absence of significant biological activity, CO_2 has no major sinks and that its concentrations are thus influenced by source strength and atmospheric transport (Pataki et al., 2005), which is conditioned by the evolution of synoptic systems (Hurwitz et al., 2004).

This paper has a twofold aim. Firstly, CO_2 origin in a rural environment is established with concentrations measured near the surface and meteorological data provided by a RASS sodar in a three-year campaign. This first objective is achieved through an original combination of directional and CO_2 distribution analyses, which consider travel time from source and mixing processes with the environment. The dataset used is long and complete enough to successfully accomplish this objective. However, trend analysis is excluded since a longer observation series would be required (Haszpra et al., 2008).

Exploring the impact of atmospheric stability on CO_2 concentrations is the second objective of this paper, and is achieved by means of a RASS sodar. The ability of this device to describe atmospheric stability has already been proved (Pérez et al., 2009). However, further exploration of these data is necessary to gain a better insight into the evolution and structure of the lower atmosphere beyond the levels investigated by conventional devices.

2. Experimental description

A three-year measuring period was used, commencing on 1 August 2002 at the Low Atmosphere Research Centre (CIBA), 41° 48′ 49″ N, 4° 55′ 59″ W, 24 km NW of Valladolid (Spain, 321 000 pp, 690 m above MSL) and 43 km SW of Palencia (Spain, 81 000 pp, 730 m above MSL). The location, Fig. 1, is a highly extensive plateau 840 m above MSL, with no relief elements, thus ensuring horizontal homogeneity. Non-irrigated crops and grass make up the surrounding vegetation, the roughness length thus being only a few centimetres.

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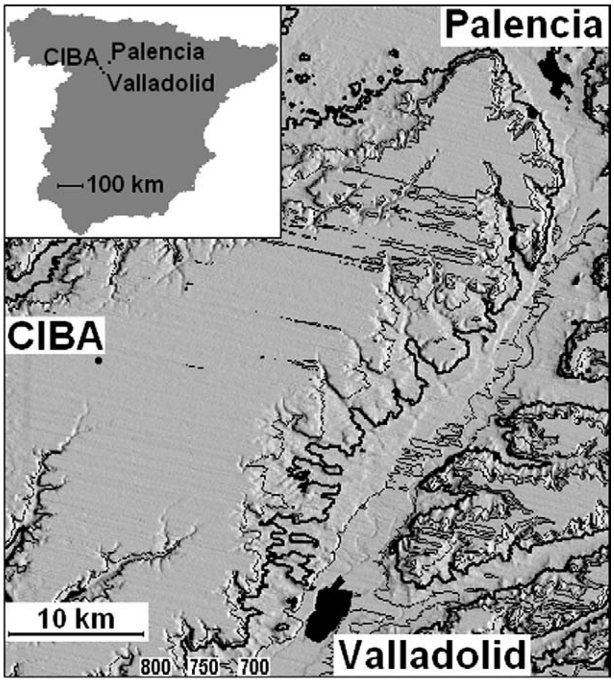

Fig. 1. Map showing the location of the measuring site, CIBA, and the cities of Valladolid and Palencia. Main level curves are also considered.

CO_2 measurements were carried out at nearly 2 m from surface using a MIR 9000 continuous analyser. Calibration of zero and span values was regularly performed using gas cylinders of ultra pure nitrogen and CO_2 AIR LIQUIDE standards of 400 ppm with a precision of 0.8 ppm. All data were continuously recorded on a DASIBI 8001 datalogger (García et al., 2008).

Meteorological variables such as wind speed, wind direction and virtual temperature were obtained from a DSDPA.90-24 sodar with RASS built by METEK GmbH (Bradley, 2008). RASS sodar data were continuously acquired, the only noticeable interruptions occurring for about 25 days (10 days in May 2003 and 15 days in June 2003). The minimum height proposed was 40 m and the maximum 500 m, measurements being limited to 20 m levels. The device generated ten-minute wind speed and virtual temperature averages, together with other variables not considered in this paper. Each value was accompanied by its plausibility code, which represents the results of the plausibility test performed on the averaged power spectra, and was used to control data quality. Data were rejected according to the standard criteria considered by the manufacturer. Finally, CO_2 and meteorological data were processed as semi-hourly mean values.

3. Results

3.1. Directional analysis

CO_2 concentrations evidenced a 379.5 ppm median and were lineally fitted, yielding an increase of 8 ppm over the whole measuring period (Pérez et al., in press). However, for our analytical purposes, they were detrended and, in order to consider only high concentrations, the 95th percentile corresponding to 20 ppm was selected. 2194 observations were above this concentration. Moreover, a second selection of these data was made with the same percentile. Only 97 observations above 77 ppm satisfied this assumption. These data occasionally appeared isolated although they frequently presented clusters that could be clearly considered as episodes. A detailed analysis of these episodes revealed that they always took place under anticyclonic conditions.

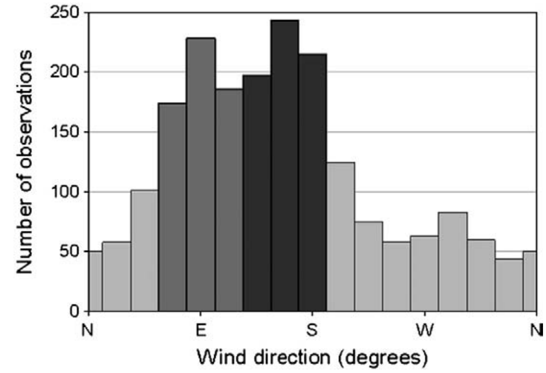

Fig. 2. Wind direction 16-sector histogram for CO_2 detrended concentrations above the 95th percentile, 20 ppm.

A 16-sector histogram based on the first selection of CO_2 concentrations and wind direction at 40 m is presented in Fig. 2, which shows two sectors associated to frequent high concentrations surrounded by a wider sector where these observations proved much less frequent. Sectors linked to the highest frequencies were established according to the main sources: the cities of Palencia and Valladolid. 30% of these observations corresponded to the Palencia sector, 33% to the Valladolid sector and 37% to the remaining directions, henceforth referred to as the rural sector. Since the Palencia and Valladolid sectors have the same angular range, frequency by a unit angle for the rural sector was approximately one third that of the Valladolid sector. Discrepancies observed between Fig. 2 maxima and the locations of the two cities should be attributed to two reasons, the first being that the plume meanders due to the orography, since plumes are emitted at a level of more than 100 m below the measuring site. The second reason is the anticyclonic turning of wind, which is more evident in layers uncoupled from the surface. Turning for the Palencia plume was higher than for the Valladolid plume due to the higher travel time.

Analysis of available wind data was also performed. Daily evolution of semi-hourly vector means of wind speed was observed at 40 m. Their median proved extremely low, 0.7 m s^{-1}. However, a noticeable contrast was obtained between day and night time. During the day, wind speed was highly variable, with a maximum of 1.6 m s^{-1} at 15 GMT, accompanied by two minima, the first below 0.3 m s^{-1} at the beginning of the diurnal period, 9.30 GMT, and a second below 0.4 m s^{-1} at the end, 20 GMT. The opposite behaviour was observed during the night time, when wind speed remained nearly constant, about 0.7 m s^{-1} from 22 to 8 GMT. Semi-hourly scalar means of wind speed were also calculated, their median being 5.2 m s^{-1}, higher than the median of vector means, although the range was similar, 1.3 m s^{-1}. Consequently, wind persistence, the ratio of vector mean to scalar mean of wind speed, sometimes used to calculate the standard deviation of wind speed (George et al., 2008) proved low. The median of semi-hourly persistence was 0.14.

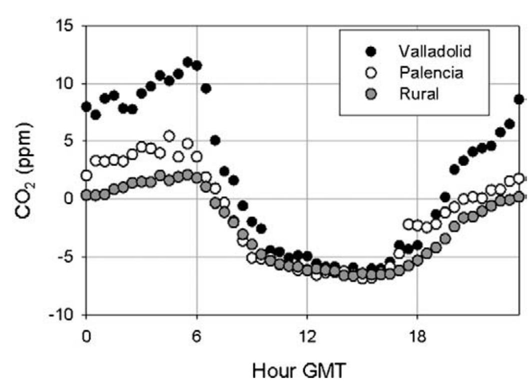

Fig. 3. Semi-hourly medians of detrended CO_2 concentrations for the three sectors proposed.