Analysis and Numerical Modelling of Black Carbon and CO_2 Concentration Peaks at a Remote Mountain Station

Silvia Ferrarese, Mirsada Cravero, Matteo Maria Musso, and Silvia Trini Castelli

Abstract Peak values of CO_2 and Black Carbon (BC) concentrations at the Plateau Rosa remote mountain site in the Italian Alps, representing a background monitoring station, are investigated. The study is conducted by analysing a long-term series of CO_2 observations and a recent dataset of measured BC concentration. To determine the potential source areas of the pollutant masses reaching the site when peak concentration events occur, numerical simulations are performed with two Lagrangian particle dispersion models, MILORD, for the long-range, and FLEXPART, for the mesoscale and regional scale. It is found that the values of the concentration show a dependence on the season, with different behaviours for the CO_2 and the BC. The analysis of some case studies using the Lagrangian atmospheric dispersion models enables to identify the main features of the synoptic and mesoscale transport.

Keywords Background monitoring station · CO_2 and Black Carbon · Peak concentrations · Numerical modelling · Lagrangian models

1 Introduction

At the Plateau Rosa station (PRS), located in the north-western Italian Alps (45.93436° N, 7.70778° E), at an altitude of 3480 m a.s.l, concentration measurements of CO_2 and Black Carbon (BC) are carried out since 1989—continuously from

S. Ferrarese · M. Cravero · M. M. Musso
Department of Physics, University of Torino, Torino, Italy
e-mail: silvia.ferrarese@unito.it

M. Cravero
e-mail: mirsada.cravero@unito.it

M. M. Musso
e-mail: matteomaria.musso@unito.it

S. Ferrarese · M. M. Musso · S. Trini Castelli (✉)
CNR-Institute of Atmospheric Sciences and Climate, Torino, Italy
e-mail: s.trinicastelli@isac.cnr.it

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1993—and since 2022, respectively. The mountainous location of PRS is suitable for conducting background measurements of greenhouse gas and pollutant concentrations, as it is located at a high altitude and it is far from local sources. Our research is aimed at studying the occurrence and origin of extreme events of pollution at such a remote site. First, the trend of the newly measured BC hourly concentrations has been analyzed and their peaks identified. Then, the possible correlation between peaks of BC and CO_2 concentrations has been investigated. It was found that depending on the seasonality, BC and CO_2 concentrations are correlated (in winter) or anti-correlated (in summer). In both cases, episodes of BC concentration peaks have been selected and numerical simulations have been performed to track the potential source areas of the pollutant masses reaching the site. For this purpose, the MILORD long-range Lagrangian Particle Dispersion Model has been applied in backward mode. The simulations enabled us to tackle the pathways followed by the air parcels for different episodes and, in particular, to detect the specific situations when the pollutant masses originated in the industrialized area of the Po Valley, a recognized pollution hot-spot in Europe. To detail such events at higher resolution, the FLEXPART Lagrangian particle model was also used. The results of the data analysis and of the MILORD and FLEXPART model simulations are presented and discussed.

2 Data Analysis and Selection of Case Studies

The analysis of the BC concentration from February 2022 to February 2023 reveals the occurrence of seven episodes with values higher than 2976 ng m^{-3} corresponding to the 99th percentile of the whole data distribution. A winter episode occurs on 6–8 February 2023 when the BC concentration values overcome 3000 ng m^{-3} (Fig. 1).

To identify the peak episodes of CO_2 in the observed series, after applying the Background Data Selection algorithm (BaDS, Apadula et al. [2]; Ferrarese et al.

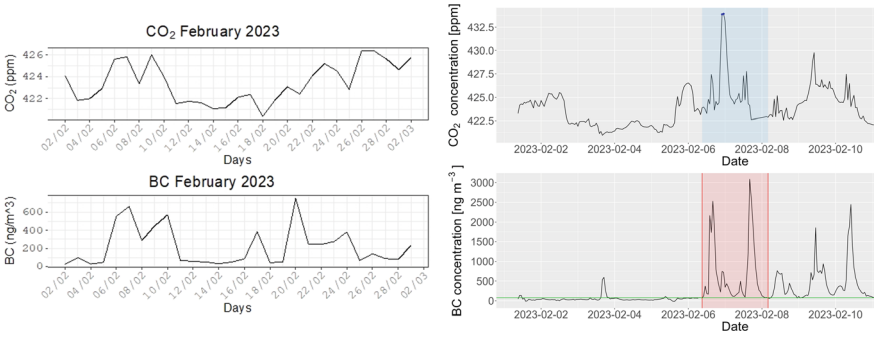

Fig. 1 Example of identification and selection of the associated peak events of CO_2 (top) and BC (bottom) measured concentrations on 6–8 February 2023: daily averages (left) and raw data (right)

[4]) to exclude significant deviations from the background, an algorithm based on the analysis of the differences between the observed hourly data and the 30-days moving averages was employed. Following this method, twelve events of CO_2 extreme concentrations longer than 24 consecutive hours and a number of shorter events were identified in the 30-year database, one of them with a concurrent peak of BC concentration, on February 6–8 2023. In Fig. 1 we report the observed data and related selection for this case, considering both the raw data and their daily averages. The correlation coefficient calculated over the daily averages of CO_2 and BC is 0.46 with a significance level of 95%, thus the two concentrations may be considered positively correlated. Considering a summer period, from June 24 to July 24 2022 (not shown), the correlation coefficient is instead negative, equal to -0.54 with a significance level of 95%, thus the two datasets can be considered anti-correlated. Such a different trend in winter and summer, indicating a dependence on the seasonality, is confirmed in the analysis of CO_2 and BC time series measured at the Alpine station of Jungfraujoch during February and May 2015 [1]. In particular, it is found that in summer time the BC concentration takes higher values than in winter, whereas the CO_2 takes its minimum concentrations during summer months. The different trends of the BC and CO_2 concentrations in the winter and summer seasons can be interpreted as follows. In summer time the stronger convection may support a larger transport of polluted air masses from the valley to the mountain top, whereas the larger vegetation activity may lead to a decrease of the CO_2 in the same period.

3 Numerical Simulations: Results and Discussion

Here we focus on two episodes, the one on February 6–8 2023 and an episode on April 1–4 2022, to provide examples of different circulation conditions leading to different impacts over the Plateau mountainous area. In particular, the event occurred on February 6–8 2023 was characterized by maxima values in CO_2 and BC data series, whereas the event in April 2022 corresponds to an extreme in the CO_2 concentration, while the BC does not show a peak in its concentration. The CO_2 event in April 2022 is one of the twelve events in the complete 30-years series that are characterized by high values during a period longer than 24 h.

To investigate these events, we performed simulations in backward mode with the Lagrangian dispersion models MILORD (Model for the Investigation of Long Range Dispersion, Trini Castelli [7]) and FLEXPART-WRF (FLEXible PARTicle–WRF, Brioude et al. [3]). MILORD is a model designed to assess long-range dispersion, in particular for accidental releases. It requires minimum information available from typical data sets (e.g. ECMWF analyses): topography, 3D wind at standard pressure levels and precipitation. It can be used both in forward and backward modes, to reproduce the areas of impact of the emitted pollutants or to identify the areas of origin of extreme events of air pollution, respectively. The computational demand of MILORD is rather limited, making it very efficient in simulation time and apt to supply fast responses in emergency applications [5, 6]. FLEXPART is a widely used

model, applied in various studies at both long-range and mesoscale to simulate the atmospheric dispersion of pollutants. The FLEXPART-WRF version is a combination where the meteorological output fields of WRF (Weather Research and Forecasting) model are used to drive FLEXPART simulations at high resolution.

The simulations were run from February 2023 8th back to the 4th with a backward release from the receptor point lasting from the 8th at 00:00 to the 6th at 12:00 UTC, and from April 2022 4th to March 30th, with a release from the 4th at 00:00 to the 1st at 12:00 UTC. The outputs have been processed and analysed in different ways: here we show the contours of the frequency of the backward trajectories in the simulation domains, determined by counting the passages of the Lagrangian particles in the cells of the post-processing Eulerian grids.

February 2023 event, depicted through the contour in Fig. 2 by MILORD simulation, is determined by a circulation transporting the polluted masses from the European north plains and mostly from the north-east industrialized areas, with another clear signal from the hot-spot of the polluted regions in the Po Valley.

In Fig. 3 examples are given of the different provenience of the air masses for the winter event in February 2023 and a summer one in July 2022, when BC concentration peaks occurred but the BC and CO_2 trends were found to be generally un-correlated. We notice also the distinct provenience of the air masses, from north–north-east in February and south-west in July case.

For the event in April 2022, we compare the results obtained with MILORD and FLEXPART models, in Fig. 4. In this case, a cyclonic circulation is characterizing the area and the air masses converging over the Plateau site come from north-west, crossing the Atlantic Ocean, south-west and north-east. FLEXPART model

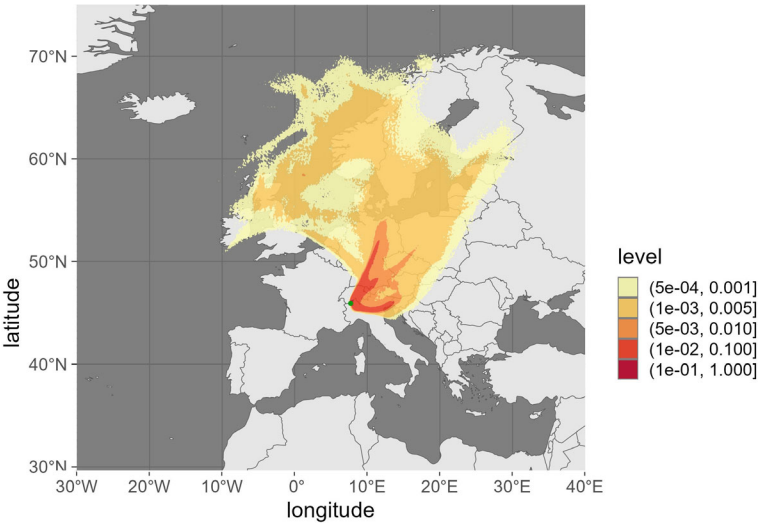

Fig. 2 Event 6–8 February 2023. Contour of the frequency of MILORD backward trajectories for the full simulation period

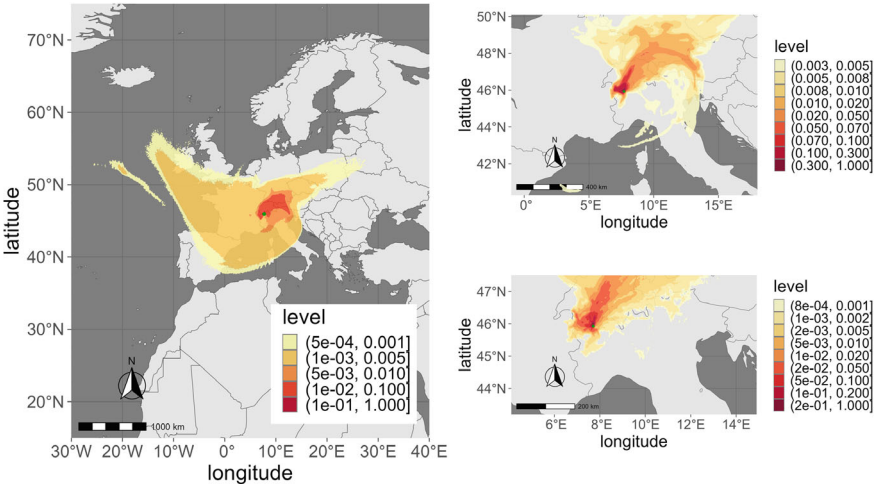

Fig. 3 Examples of the pattern of the Lagrangian particles for two time frames in February 2023 (left) and July 2022 (right), MILORD model

enables highlighting the stronger contribution from north-east, of masses crossing the Alpine regions in Switzerland and Austria. The cyclonic circulation was found to characterize most of the extreme events of CO_2 concentrations, indicating a clear dependence of them on the synoptic conditions.

4 Conclusions

A thorough analysis of 30 years of CO_2 observed data at the background monitoring station Plateau Rosa, in the Italian Alps, led to the identification of twelve concentration extremes. Jointly, the analysis of a one-year database of Black Carbon (BC) concentrations, measured recently at the same station, enabled us to single out their peaks and to assess the possible correlation with CO_2 peaks or its longer-term extremes. A certain dependency on the seasonality was found, for which BC and CO_2 appeared to be correlated in winter time and uncorrelated in summer time. We interpreted such differences as related to the thermal mountain-valley circulation, transporting polluted air masses from the valley to the mountain top, and to the contribution of the vegetation in removing the CO_2 during the summer months.

The peak concentration events were studied by performing backward numerical simulations with two Lagrangian particle dispersion models, MILORD for the long-range and FLEXPART for the regional scale. The results showed that the potential source areas of such high concentrations are the industrialized regions of northern Europe and the pollution hot spot of the Po Valley in Italy. The combination of simulations with long-range and regional models allows detailing the dispersion

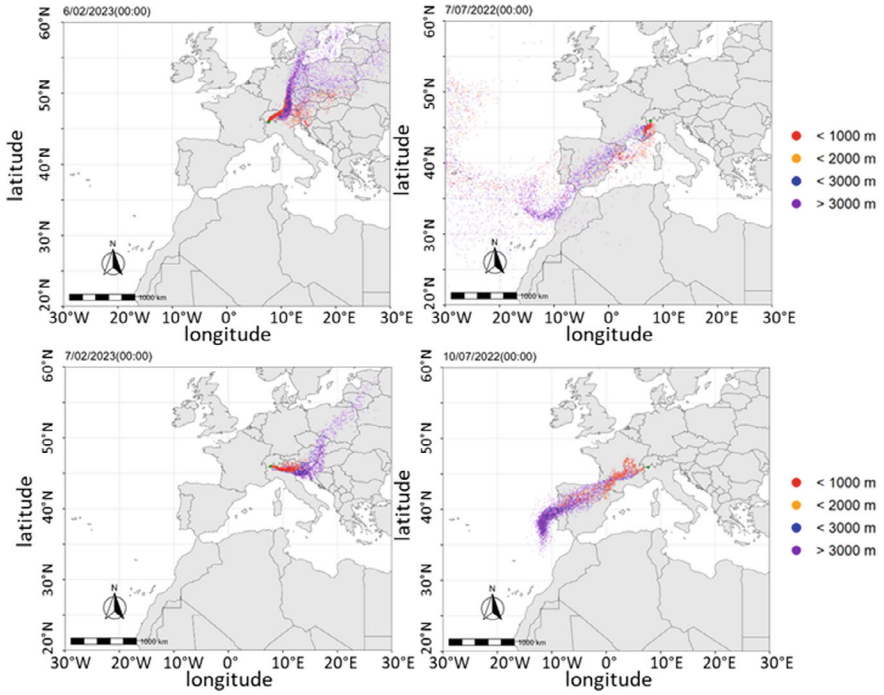

Fig. 4 Event 01–04 April 2022. Contours of the frequency of the backward trajectories for MILORD (left) and for two nested domains in WRF-FLEXPART (right, top and bottom)

features at the different scales, and it is an efficient approach to study the rare events of peak concentrations at remote monitoring stations, like Plateau Rosa which is an established site to assess the background state of the atmosphere.

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