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DISPERSION MODELLING OF RARE EXTREME CO_2 CONCENTRATION EVENTS DETECTED AT ALPINE SITES

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Abstract: Carbon dioxide (CO_2) is one of the main greenhouse gases and it is a key quantity in the study and evaluation of climate change. CO_2 atmospheric concentrations are routinely monitored at remote sites in order to evaluate the concentration background. The complete set of measured data includes also the presence of short episodes not representative of the background CO_2 levels as consequence of local or regional transport. In the present work data collected at the Alpine station of Plateau Rosa on Italian Alps are considered, and the events characterized by high concentration are identified. In order to study the transport process during high concentration events, the dispersion models MILORD and FLEXPART-WRF are applied. Results show that the source areas are located over the European highly industrialized areas.

Key words: *CO_2 atmospheric concentration, Plateau Rosa site, MILORD, FLEXPART-WRF.*

INTRODUCTION

The main driver for the climate change is the increasing concentration of greenhouse gases among which the carbon dioxide (CO_2) has an important role as consequence of its radiative forcing (IPCC, 2013). Atmospheric CO_2 monitoring is fundamental in order to evaluate the CO_2 concentration trend and its variability in time. For this reason, CO_2 is constantly monitored at several locations around the world and in particular at remote sites. These sites are far from urbanized and polluted areas, they are little affected by local sources and transport, and they are suitable for evaluation of background levels.

In Europe, some observatories are located in Alpine regions at high altitudes where the polluted masses originated in the lower atmospheric layers can seldom arrive. However, in very rare occasions, air masses with an abnormally high content of greenhouse gases can reach the mountain stations, resulting in extreme concentration events (Uglietti et al., 2011, Ferrarese et al., 2015). The analysis of the CO_2 concentration time series permits identifying the high concentration events. In order to identify the potential source areas of CO_2 high concentration events, Lagrangian particle dispersion models (LPDM) can be applied.

In this work, two high concentration events have been identified in the hourly records at high altitude European stations and in particular at the site of Plateau Rosa station in the north-western Alps.

The events were studied by performing backward release simulations with the Lagrangian dispersion models MILORD (Model for the Investigation of Long Range Dispersion, Trini Castelli, 2012) and FLEXPART-WRF (FLEXible PARTicle – WRF, Brioude et al., 2013). MILORD is an LPDM designed to assess long-range transport and dispersion requiring the minimum information available from typical data sets (e.g. ECMWF analyses): topography, 3D wind at standard pressure levels and precipitation. This characteristic makes MILORD very useful for studying accidental release, and for identifying the areas of

origin of extreme events of air pollution. Moreover, MILORD is very efficient in computational time (Ferrarese and Trini Castelli, 2019).
FLEXPART has been used in many studies to calculate long-range and mesoscale dispersion of air pollution; FLEXPART-WRF works with WRF (Weather Research and Forecasting) model using the fields computed by WRF at high resolution as meteorological input data.
The results show the existing differences in the performance among the two models and how they can be both useful tools in identifying potential sources.

CO2 MEASUREMENT SITE AND SELECTED PEAK EVENTS

The Alpine station of Plateau Rosa (PRS, 7.71°E, 45.93°N, 3480 m a.s.l.) is located in the north-western Italian Alps, near Mt. Cervino, upon a large snow-clad mountain plateau surrounded by the glacier. CO_2 concentration has been monitored at the station since 1989 and continuously since 1993. PRS is part of two international nets: Integrated Carbon Observation System (ICOS) and Global Atmosphere Watch (GAW). In our work, we applied the Background Data Selection (BaDS) algorithm to the PRS data series to exclude any significant deviation from the background (Apadula et al, 2019). Then, we developed, and applied, an algorithm to identify extreme CO_2 events. This process resulted in the recognition of twelve events with high concentration of CO_2 in the time series of about thirty years. The scarcity of these events confirms that the majority of observations gathered at PRS are fully representative of the background state of the atmosphere. However, in rare occasions, air masses with a high concentration of pollutants can reach the station generating extreme outliers in the data.
In this work two events are studied: a recent one in November 2017 and a past one in February 2004 (Figure 1). The November 2017 event lasted almost three days with a peak in PRS CO_2 concentration of 421.31 ppm measured at 14:00 UTC on 8 November. Figure 1a shows the hourly series from PRS compared with ones from two other Alpine monitoring stations: the Swiss Jungfraujoch (JFJ) and the Austrian Sonnblick (SNB). Data suggest that JFJ experienced the same event, while SNB was not affected. In February 2004 the CO_2 concentration series at PRS showed two consecutive peaks of 399.97 ppm on 19 February at 6:00 UTC and 407.89 ppm on 23 February at 15:00 UTC (Figure 1b)

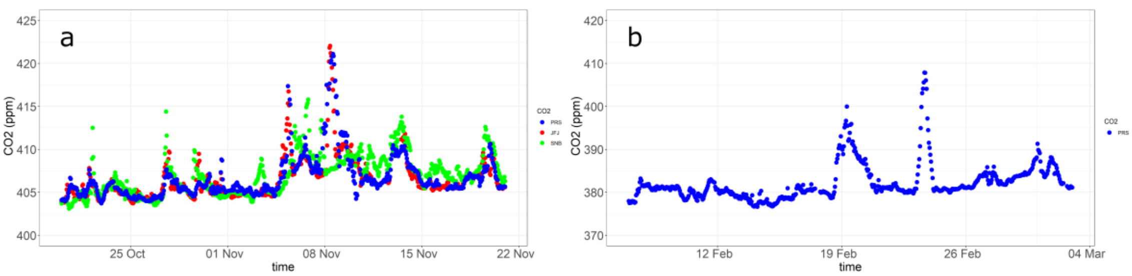

Figure 1. (a) CO_2 data at Plateau Rosa station (blu points), Jungfraujoch station (red points) and Sonnblick station (green points) during the November 2017 event, (b) CO_2 data at Plateau Rosa station (blue points) during the February 2004 event.

MILORD AND FLEXPART-WRF SIMULATIONS

Both episodes were analysed with the application of the WRF model to obtain highly resolved meteorological fields, considering a parent domain and a nested one with a resolution of 9 km and 3 km respectively and 50 vertical levels. Several tests have been performed with FLEXPART-WRF varying the particle time release from one hour to the total time event. Obtained results with 18 hours long release around the peak time of 100000 particles are shown in Figure 2. In both cases, two main air fluxes are present: one flux arrived from the western boundary of the domain (i.e.: eastern France) at upper atmospheric levels and the second, which includes most of the particles, travelled inside the Planetary Boundary Layer (PBL) above the highly industrialized regions in the Po Valley. This second flux seems to be the most probable source of the studied events. In the simulation of the second peak on February 23 2004 (not shown) the source areas seem to be in the European plains north of the Alps.

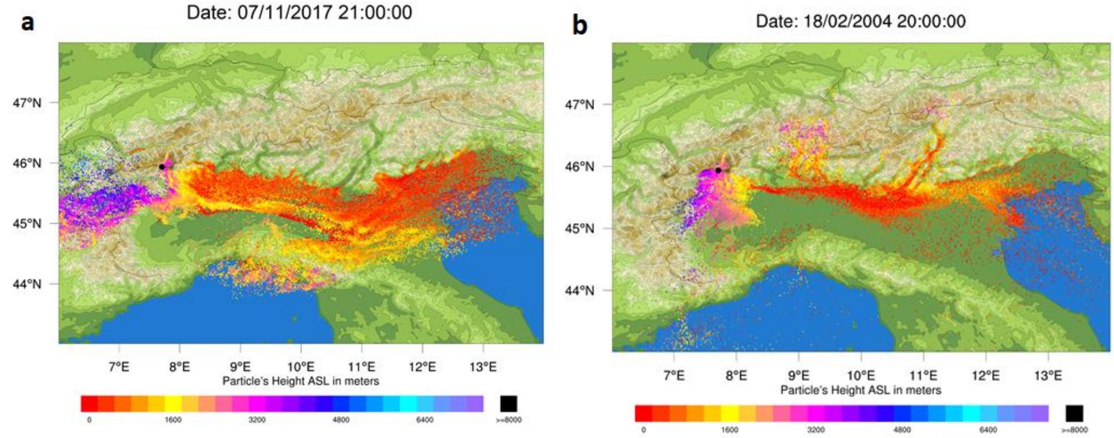

Figure 2: FLEXPART-WRF tracer clouds from PRS station in the case study of (a) November 2017 and (b) February 2004

Additional backward simulations with FLEXPART-WRF releasing 20000 particles in 1 hour from JFJ and SNB were performed. Both FLEXPART-WRF simulations started on 8 November 2017 in the morning and ended on 7 November 2017 at 00:00 UTC.

In the release from JFJ, the simulated particles show similar trajectories compared with the PRS release results. As shown in Figure 3a, two main air fluxes were present. The first one was coming at a high altitude from the eastern boundary of the domain. The latter, which consists in the majority of the particles, spans the Po Valley dwelling in the lower atmospheric strata, well inside the PBL. This result confirms that the extreme concentration event which affected PRS also involved JFJ.

The simulated particles in the release from SNB show a completely different pattern compared to PRS and JFJ. The run highlights the presence of a single air flux (Figure 3b) that reaches the station from the western boundary of the domain. Air particles travel above the PBL flying over scarcely populated areas such as the Adriatic Sea and the Istria region. The output from this simulation confirm that SNB was not affected by the event.

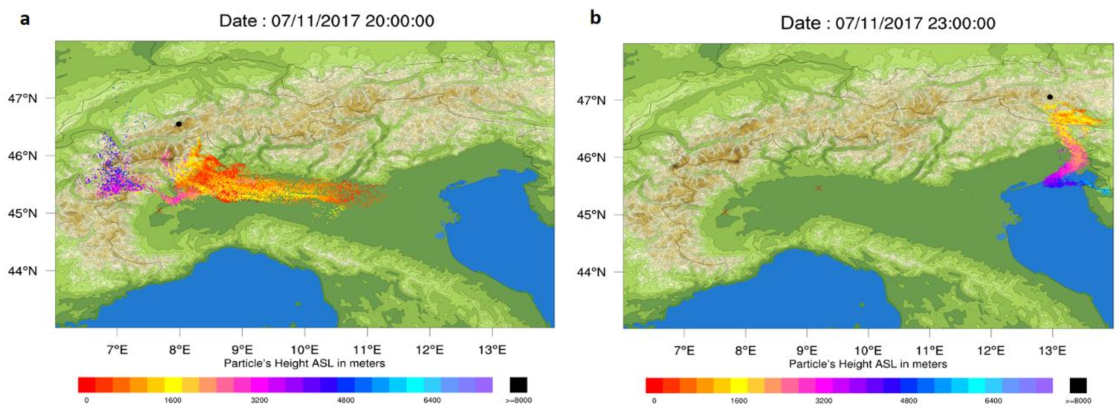

Figure 3. FLEXPART-WRF tracer clouds in the case study of November 2017 (a) from JFJ station and (b) from SNB station

A two-days long simulation was performed using the long-range Lagrangian particle model MILORD in order to study the November 2017 event. The meteorological input is given by the ECMWF analyses on a 0.5 × 0.5 degrees gridded domain and 15 vertical pressure levels. The particle emission of 100000 particles lasted 1 hour on 8 November from 14:00 UTC until 13:00 UTC. The results of the first day of simulation show two main different signals: one corresponding to masses coming from the eastern industrialised regions of Italy (Po Valley) and travelling at a prevalent height below 1000 m, the other corresponding to masses coming from west and north-west (western France) with a prevalent travelling height above 3000 m (Figure 4a). February 2004 event was studied with a similar MILORD simulation but with a release time

of 8 hours. Also in this case the main air fluxes arrived from the low layers over the Po Valley and high levels from the west direction (Figure 4b).
At the regional scale, MILORD replicates the results found with FLEXPART-WRF, highlighting the main contribution from the Po Valley.

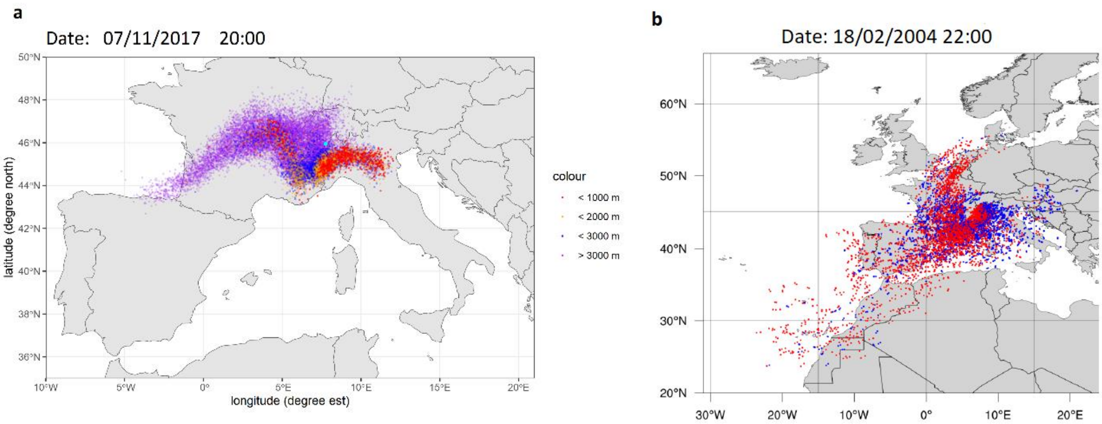

Figure 4. (a) MILORD tracer clouds from PRS in the case study of November 2017 (red, orange, blue and purple colours are relative respectively to particle lower than 1000 m, between 1000 m and 2000 m, between 2000 m and 3000 m, and higher than 3000 m a.s.l.(b) MILORD tracer clouds from PRS in the case study of February 2004 (red and blue colours are relative respectively to particle higher or lower than 3489 m a.s.l., station altitude)

CONCLUSIONS

During almost thirty years of continuous measurements, the Alpine monitoring station of Plateau Rosa has experienced only twelve extreme CO_2 concentration events confirming that Plateau Rosa station is extremely well suited to investigate the background atmospheric state. We studied two events applying simulations consisting of backward particle releases with the FLEXPART-WRF and MILORD Lagrangian dispersion models. According to the results of those simulations, the most plausible sources of the events are air masses which dwelled inside the PBL above the industrialized areas before reaching the monitoring stations. The coupling of FLEXPART and WRF allows to obtain high horizontal resolution results and to capture in detail the evolution of the transport event. MILORD model, despite being a long-range model, is able to correctly identify the flows carrying air parcels to the stations. The two models with complementary features, respectively detailed results and reduced computational demand, produced comparable results and can be applied to investigate the source of high CO_2 values measured at Alpine remote stations.

REFERENCES

Apadula F., Cassardo C., Ferrarese S., Heltai D., Lanza A., 2019, Thirty years of atmoapheric CO2 observations at the Plateau Rosa Station, Italy. *Atmosphere*, **10** , 418

Brioude J., Arnold D., Stohl A., Cassiani M., Morton D., Seibert P., Angevine W., Evan, S., Dingwell, A., Fast, D.J., Easter R.C., Pisso I., Burkhart J, Wotawa G., 2013: The Lagrangian particle dispersion model FLEXPART-WRF version 3.1. *Geoscientific Model Development*, **6**, pp. 1889–1904..

Ferrarese, S., Apadula, F., Bertiglia, F., Cassardo, C., Ferrero, A., Fialdini, L., Francone, C., Heltai, D., Lanza, A., Longhetto, A., 2015, Inspection of high–concentration CO_2 events at the Plateau Rosa Alpine station. *Atmos. Pollut. Res.*, **6**, 415–427

Ferrarese S. and Trini Castelli S., 2019. Detection of CO_2 source areas using two Lagrangian particle dispersion models, at regional scale and long range. Proceedings of the 19th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Bruges, Belgium, 3-6 June 2019, 5 pages

IPCC. Climate Change 2013: The Physical Science Basis. In Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, New York, NY, USA, p. 1535.

Trini Castelli, S., 2012: *MILORD-reload. Model for the Investigation of Long Range Dispersion. Internal Report* ISAC-TO/02-2012, 10 September 2012

Uglietti, C., Leuenberger, M., Brunner, D., 2011: European source and sink areas of CO_2 retrieved from Lagrangian transport model interpretation of combined O_2 and CO_2 measurements at the high alpine research station Jungfraujoch. *Atmospheric Chemistry and Physics*, **11**, 8017– 8036.