Dispersion modelling of rare extreme CO_2 concentration events detected at Alpine sites

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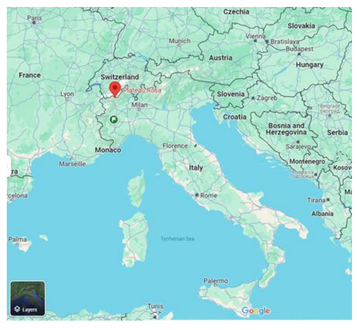
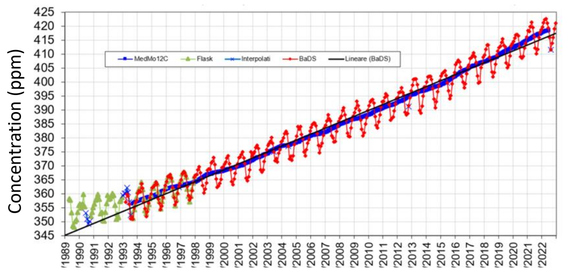
Absract Carbon dioxide (CO_2) is one of the main greenhouse gases and it is a key quantity in the study and evaluation of climate change. CO_2 atmospheric concentrations are routinely monitored at remote sites in order to evaluate the concentration background. The complete set of CO_2 measured data includes also the presence of short episodes not representative of the background levels as consequence of local or regional transport. In the present work data collected at four Alpine stations are considered, and the events characterized by high concentration are identified in the time series of Plateau Rosa station. 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.

Plateau Rosa site





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).

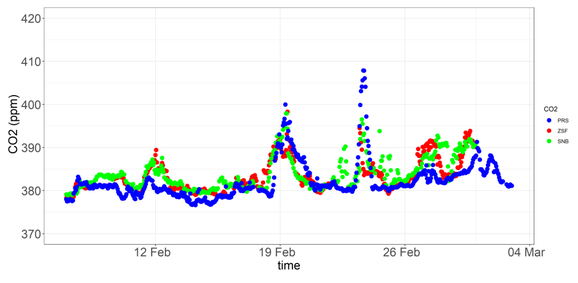
Extreme event selection

The PRS hourly CO_2 concentration series now covers more than thirty years ranging from 1993 to 2024. The atmospheric background values are identified applying the Background Data Selection (BaDS) algorithm to the series (Apadula et al., 2019). The extreme events are detected comparing the raw concentration 24-hours moving average with the background monthly moving average. The episodes longer than 1 day and with deviation exceeding 6σ are classified as extreme CO_2 concentration events. The scarcity of these events (12 events in the whole series lasting more than 30 years) confirms that the majority of observations gathered at PRS are fully representative of the background state of the atmosphere.

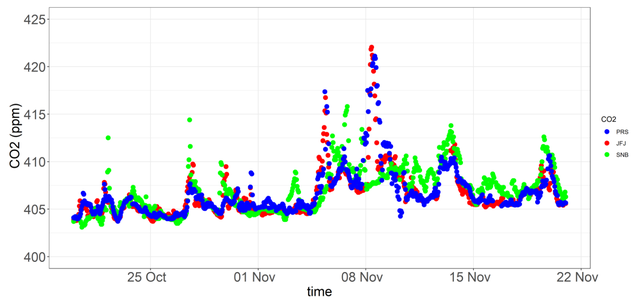
Date	Max deviation (ppm)	Mean deviation (ppm)
12 - 16 December 1995	14,8	9,0
12 - 15 February 1996	12,8	5,8
20 - 25 September 1996	14,4	3,2
2 - 6 December 1997	15,3	7,7
8 -12 November 1999	18,2	7,3
27 - 29 November 2003	14,7	7,3
18 - 20 February 2004	19,8	8,1
19 February - 1 March 2005	15,7	6,5
28 February -8 March 2009	17,0	5,9
24 - 27 February 2013	13,4	6,7
4 - 10 November 2017	15,2	4,4
30 March - 4 April 2022	11,6	6,1

The events studied in this work are highlighted in yellow.

Two case studies



Two events were measured in February 2004 at PRS (in blue), the first (18-20 February) is classified as extreme, the second (23-24 February) as instantaneous.
The German station of Zugpitze (ZSF, in red) and the Austrian station of Sonnblick (SNB, in green) measured high concentrations during the first episode, whereas they detected only partially the second episode (Ferrarese at al. 2015).



On 4-10 November 2017 an extreme event occurred. Here the hourly series at PRS (in blue) is compared with ones at two other Alpine monitoring stations: the Swiss Jungfraujoch (JFJ, in red) and the Austrian Sonnblick (SNB, in green). Data suggest that JFJ experienced the same event, while SNB was not affected.

LPDM simulations

The two case studies were analyzed by two Lagrangian Particle Dispersion Models: **FLEXPART-WRF** (FLEXible PARTicle - Weather Research & Forecasting, Brioude et al., 2013) and **MILORD** (Model for the Investigation of Long Range Dispersion, Trini Castelli, 2012), in **backward mode**.

In **FLEXPART-WRF** model the meteorological input fields are provided by WRF (Weather Research and Forecasting model). Here WRF was driven by 3-hours ECMWF ERA5 data and its grid setup consisted in two nested domains with 9 km and 3 km of horizontal resolution and 50 vertical levels.

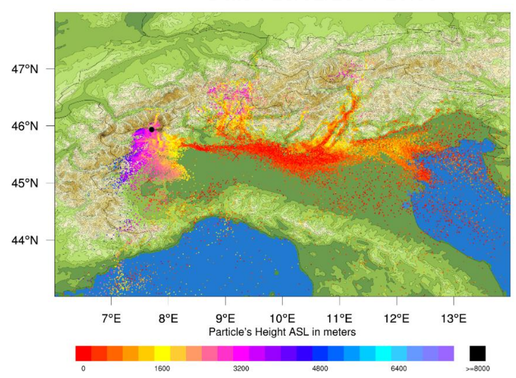
MILORD is a 3-D long-range Lagrangian particle model. The model was initialized with 6-hours ECMWF analyses on a domain covering whole Europe.

Results

February 2004

PRS

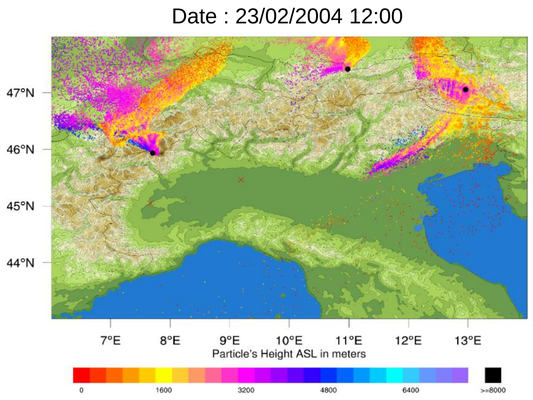
Date : 18/02/2004 20:00



FLEXPART-WRF simulation from 19/02/2004 15:00 UTC to 17/02/2004 14:00 UTC
Release time: 18 hours
Number of particles: 100000

PRS-ZSF-SNB

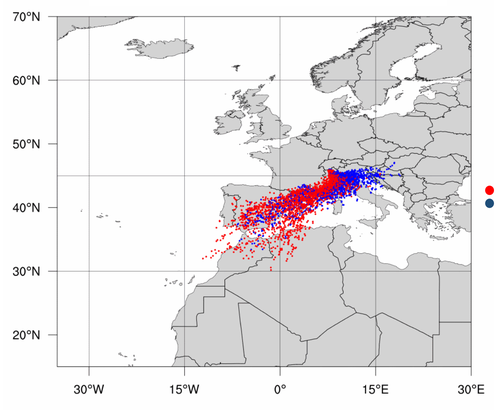
Date : 23/02/2004 12:00



FLEXPART-WRF simulation from 24/02/2004 01:00 UTC to 22/02/2004 00:00 UTC
Release time: 18 hours
Number of particles: 300000

PRS

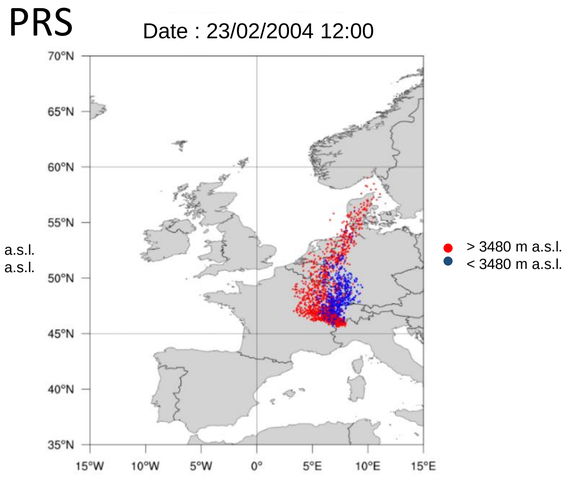
Date : 19/02/2004 18:00



MILORD simulation from 20/02/2004 21:00 UTC to 18/02/2004 13:00 UTC
Release time: whole simulation time
Number of particles: 100 every 36 minutes

PRS

Date : 23/02/2004 12:00

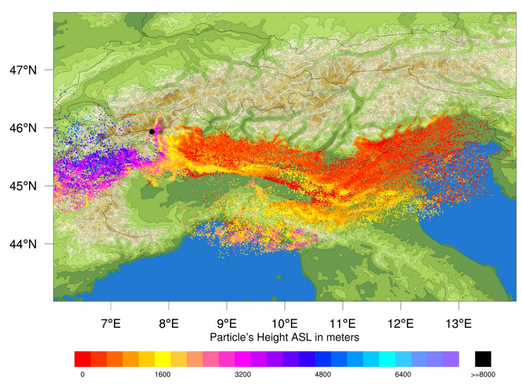


MILORD simulation from 24/02/2004 03:00 UTC to 23/02/2004 03:00 UTC
Release time: whole simulation time
Number of particles: 100 every 36 minutes

November 2011

PRS

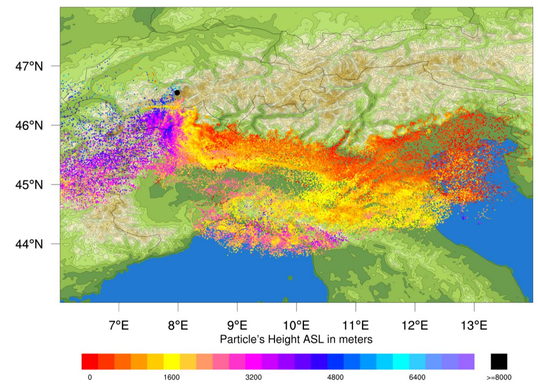
Date : 07/11/2017 21:00



FLEXPART-WRF simulation from 08/11/2017 20:00 UTC to 06/11/2017 00:00 UTC
Release time: 18 hours
Number of particles: 100000

JFJ

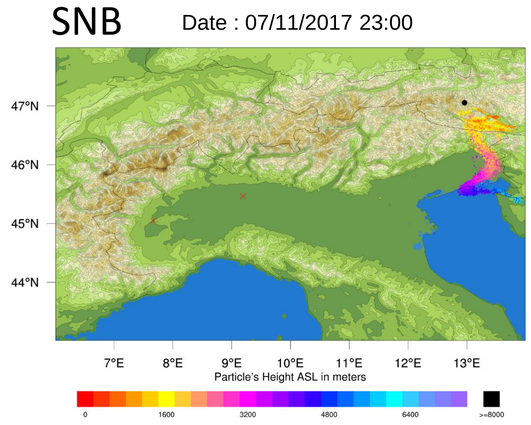
Date : 07/11/2017 21:00



FLEXPART-WRF simulation from 08/11/2017 20:00 UTC to 06/11/2017 00:00 UTC
Release time: 18 hours
Number of particles: 100000

SNB

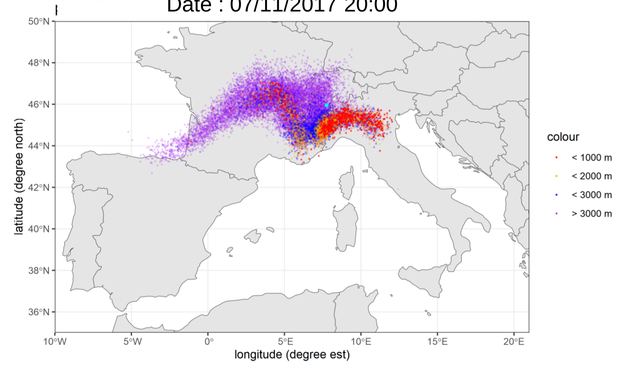
Date : 07/11/2017 23:00



FLEXPART-WRF simulation from 08/11/2017 11:00 UTC to 07/11/2017 00:00 UTC
Release time: 1 hour
Number of particles: 20000

PRS

Date : 07/11/2017 20:00



MILORD simulation from 08/11/2017 13:00 UTC to 06/11/2017 13:00 UTC
Release time: 1 hour
Number of particles: 10000

Conclusions

Both models show that the most plausible sources of the events are air masses that travelled 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

- J. Brioude, D. Arnold, A. Stohl, M. Cassiani, D. Morton, P. Seibert, W. Angevine, S. Evan, A. Dingwell, J. D. Fast, R. C. Easter, I. Pisso, J. Burkhart, and G. Wotawa. *The Lagrangian particle dispersion model FLEXPART-WRF version 3.1*. In: *Geoscientific Model Development* 6.6 (2013), pp. 1889–1904..
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