19th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
3-6 June 2019, Bruges, Belgium

DETECTION OF CO_2 SOURCE AREAS USING TWO LAGRANGIAN PARTICLE DISPERSION MODELS, AT REGIONAL SCALE AND LONG RANGE

Silvia Ferrarese[1] and Silvia Trini Castelli[2]

[1]Department of Physics, University of Torino, Torino, Italy
[2]Institute of Atmospheric Sciences and Climate, National Research Council, Torino, Italy

Abstract: Two extreme CO_2 concentration events were detected in February 2004 at the mountain station of Plateau Rosa in the Italian Alps. The meteorological model WRF was used to study the evolution of the meteorological fields and to identify the deterministic trajectories of the polluted air masses. Here, the case study is examined applying two Lagrangian particle dispersion models in backward mode, in order to trace the provenience of the CO_2 mass. FLEXPART-WRF model was used at the regional scale, MILORD model was applied on long-range. The deterministic trajectories are verified against the models' results. Despite the differences in scales and parameterizations, the two models provide very similar patterns of the particle clouds.

Key words: *CO_2 concentration peaks, mountain site, trajectory models, Lagrangian particle stochastic models.*

INTRODUCTION

CO_2 concentration in the atmosphere is a key quantity for assessing the global greenhouse effect and the actual climate change. Its concentration is constantly monitored at several localities around the world, particularly in sites far from urbanized and polluted areas with the aim to capture its background evolution. Mountain observatories are unique sites in Europe for their altitude and distance from anthropic environments, thus they are suitable to measure background concentration of greenhouse gases. Sometimes the CO_2 time series could be inferred by local sources or transport at short and long scale showing extreme events of very high or low concentration. These events are usually identified and deleted in the computation of background data but they can be useful in the localization of source and sink areas (Uglietti at al. 2011).

In Italy, at the station of Plateau Rosa (7.71°E, 45.93°N, 3480 m a.s.l) in the Italian Alps near Mt. Cervino, the CO_2 concentration has been measured since 1989. Two extreme CO_2 concentration events were identified in February 2004 and were analysed (Ferrarese et al. 2015) with the use of the regional meteorological model WRF (Skamarock et al. 2008), to study the evolution of the meteorological fields and to identify the deterministic trajectories of the polluted air masses during the occurrence of the CO_2 peaks.

In this paper, the case study has been re-examined applying two Lagrangian particle dispersion models at two scales, in order to better reproduce the atmospheric motions, which are characterized by turbulent and stochastic processes. At the regional scale FLEXPART-WRF model was used (Briounde et al. 2013) and for the long-range MILORD model was applied (Trini Castelli 2012, Boetti et al., 2017). FLEXPART-WRF was set in backward mode using in input the WRF simulated meteorological fields, which were in turn computed using the ECMWF analyses as input. MILORD simulations, driven directly by the ECMWF analyses, were run for the first time in the backward-mode, after some preliminary sensitivity analysis.

THE CASE STUDY

CO_2 atmospheric concentration is measured at the Alpine site of Plateau Rosa (PRS, 7.71°E, 45.93°N, 3480 m a.s.l.) in the Italian Alps near Mt. Cervino (Figure 1) since 1989. PRS site is one of the highest European atmospheric monitoring station and it is far from potential pollution sources. The station is present in the Global Atmosphere Watch (GAW) program as "regional station" and actually it is candidate in ICOS (Integrated Carbon Observation System) Research Infrastructure.

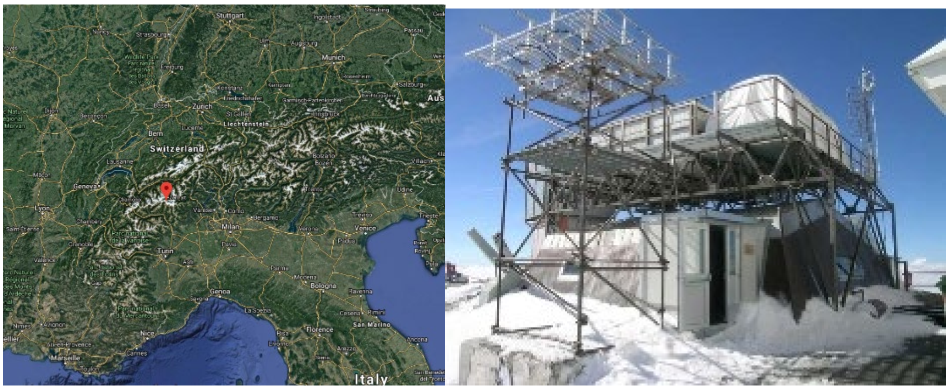


Figure 1: Geographical position of the station of Plateau Rosa (a) and a picture of the station (b)

Measured data are routinely selected by a filtering technique to identify the background values that are fundamental for climatology studies. Here we are interested in non-filtered data, where occasionally intense events occur in consequence of transport at long scale (Apadula et al., 2003, Ferrarese et al., 2015). During February 2004, two extreme events in CO_2 concentration were captured at PRS station, showing an increase in CO_2 concentrations respectively of about 20 ppm and 28 ppm (Figure 2). The same events were registered at the Alpine stations of Zugspitze-Schneefernerhaus (47.42°N, 10.98°E, 2656 m a.s.l.) and Sonnblick (47.05°N,12.95°E, 3106 m a.s.l.).

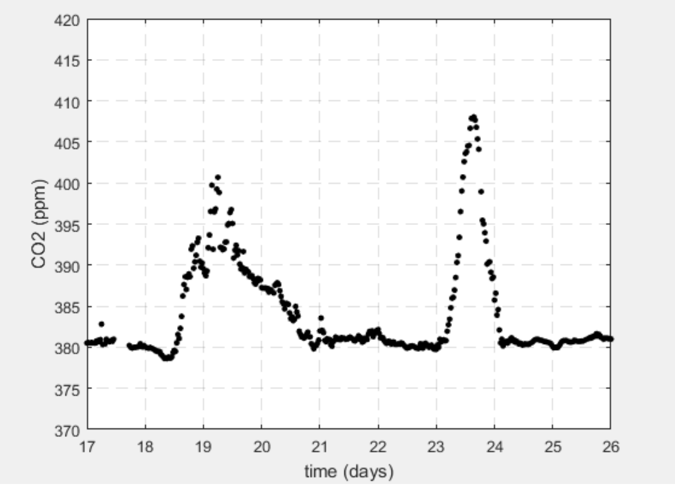
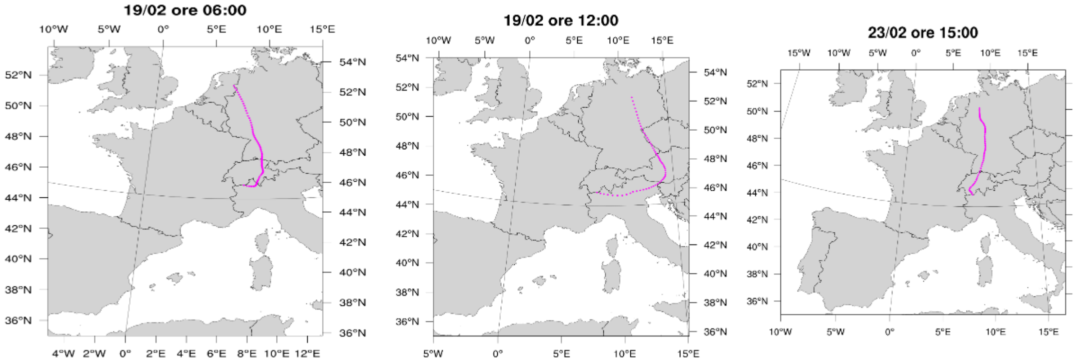


Figure 2: Time evolution of the CO_2 concentration during the two peak events in February 2004

The first event started on 18 February at 13:00 UTC, reached the maximum values of about 401 ppm on 19 February at 6:00 UTC and ended on 20 February evening. The second event was more intense and shorter (22 hours), from 23 February at 04:30 UTC to 24 February at 02:30, with a single isolated peak of about 408 on 23 February at 15:30 UTC.

THE ANALYSIS THROUGH DETERMINISTIC AND STOCHASTIC APPROACHES

The two events were previously studied using deterministic trajectories, which were computed every 3 hours by interpolation of WRF output fields (Ferrarese et al., 2015). The results showed that during the first event the air mass arrived over PRS station initially from North, then outflanked the eastern side of the Alps and moved above the Po Valley travelling at low altitude (Figures 3 a-b). During the second event the wind again blew from North sectors moving at low altitude and reached PRS without travelling over the Po Valley (Figure 3c).


19/02 ore 06:00

19/02 ore 12:00

23/02 ore 15:00

Figure 3. Trajectories (2 days length) from WRF fields interpolation

In the present work, the analysis has been deepened using more sophisticated numerical tools: FLEXPART-WRF model working at regional scale and MILORD model for the long-range scale. Both of them are Lagrangian particle stochastic models, here working in backward mode. Also in application to long-range and transnational transport, using dispersion models has the advantage of a more reliable reproduction of the pollutant distribution since they can reproduce the stochastic nature of the atmospheric motions, not captured by the trajectories approach.

In FLEXPART-WRF model the input meteorological fields are provided by WRF to FLEXPART and the two models run independently. Here, WRF was driven by 6-hours ECMWF analyses and its grid setup consisted of two domains with grid spacing respectively of 26 km and 9 km and 28 vertical levels. The coarse grid covered Europe (from 36°N to 59°N in latitude and from 6°W to 17°E in longitude) and the nested grid zoomed over the Alpine region (from 43°N to 50°N in latitude and from 6°E to 14°E in longitude). The selected schemes for the microphysics, planetary boundary layer, surface processes, radiation and clouds are listed in Table 1.

Table 1**.** WRF model schemes adopted in the simulations

Microphysics	Long wave radiation)	Short wave radiation)	Surface layer	Land-surface	PBL)	Cumulus
Lin	RRTM	Dudhia	MM5	5-layer TD	YSU	Kain-Fritsch

In FLEXPART simulations, 10^5 particles arrived at PRS site, in a box of 0.1° in longitude and latitude and vertical extension of 80 hPa, from 680 to 600 hPa. The horizontal output grid was kept identical to the horizontal WRF grid, whereas in the vertical two levels at 100 m and 10000 m above the surface were considered. The simulation time step was variable and limited by Lagrangian time scale. Two simulations were performed in correspondence to the two events, the emission lasted for all simulation period, respectively from 18th February 13:00 UTC to 20th February 21:00 UTC, and from 23th February 03:00 UTC to 24th February 03:00 UTC.

FLEXPART-WRF confirmed the results provided by the interpolation of WRF wind fields, at the same time better detailing the time evolution and the spread of the tracer cloud during the episode. In particular, FLEXPART-WRF simulated particles arriving to PRS not only from N direction, but also coming from E, namely from the Po Valley (Figure 4a). Later on, at the time of the first peak (Figure 4b), the tracer cloud shows a provenience mostly from South-West and East. It is worth noticing that the particles arriving from the Po Valley are all travelling at heights below the station altitude, while from N and SW they are reaching the site also from higher levels. The second event is characterized by a tracer cloud arriving from N and composed by particles travelling both at lower and higher levels than PRS altitude (Figure 4c).

Both approaches, the trajectories, based on WRF-fields interpolation, and FLEXPART-WRF model, worked at regional scale but the stochastic approach of the second one can produce a more detailed description of the provenience and sources of the measured CO_2 concentration.

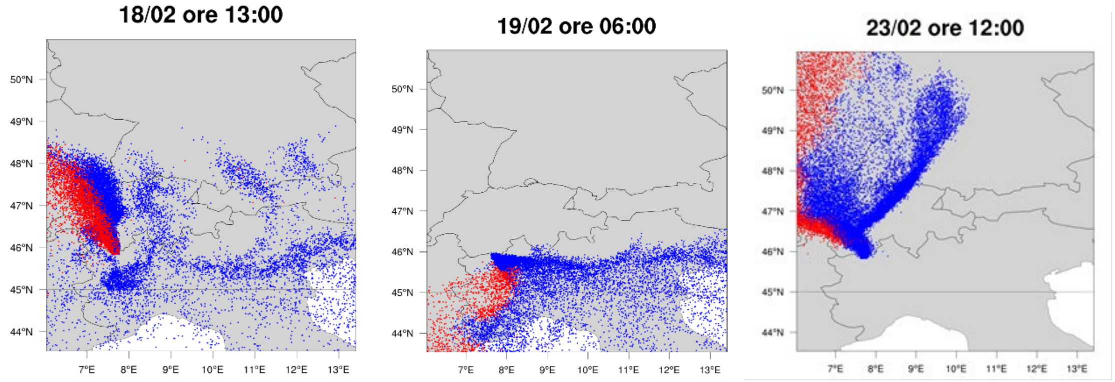


Figure 4. Tracer clouds from FLEXPART-WRF at the beginning of the first event (a), when the CO_2 concentration reached the maximum value (b), and during the second event (c). Red and blue colours are relative respectively to particle higher or lower than 3489 m (station altitude).

MILORD (Model for the Investigation of Long Range Dispersion) is a 3-D long-range Lagrangian particle model (Trini Castelli, 2012). The model was initialized with 6-hours ECMWF analyses on a domain covering whole Europe (latitude from 15°N to 80°N, longitude from 60°W to 45°E). MILORD simulation was setup with a backward release of 100 particles at each time step (2160 s), the receptor box had a horizontal extension of 0.01°× 0.01° in longitude and latitude and a vertical depth equal to 50 hPa (lower boundary 650 hPa and upper boundary at 600 hPa) centred in the position of PRS station. The simulation covered the period between 18 February at 13:00 UTC and 20th February at 21:00 UTC for the first event, between 23rd February at 03:00 UTC and 24th February at 03:00 UTC for the second event.

The results (Figure 5) show that on the 18th the particles arrived at PRS from N-NW and SW, with a smaller contribution of particles from E and the Po Valley. In the first hours of the 19th, most of the cloud arrives from SW and the contribution from E rapidly increases. The comparison between results from FLEXPART-WRF regional model (Figure 4) and MILORD long-range model (Figure 5) shows a good agreement between the two tracer clouds, especially on 19th February, when the CO_2 peak occurred. In the second event the tracer cloud simulated by MILORD came from N (Figure 5c), with particles travelling both at lower and higher levels than PRS altitude, in very good agreement with FLEXPART-WRF.

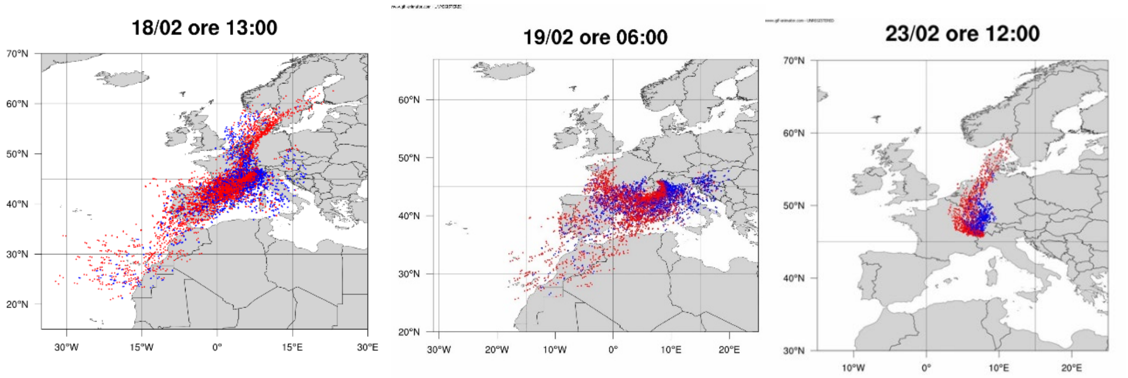


Figure 5. Tracer clouds from MILORD at the beginning of the first event (a), when the CO2 concentration reached the maximum value (b), and during the second event (c). Red and blue colours are relative respectively to particle higher or lower than 3489 m (station altitude).

CONCLUSIONS

Two episodes of extreme high CO_2 concentrations recorded at a mountain site, where no local sources of pollutants are present, have been analysed using traditional deterministic trajectories and two Lagrangian particle stochastic models, FLEXPART-WRF and MILORD, running at regional and long-range scales. The two models provided very similar dispersion patterns despite their different scales and different physical parameterizations. In practical applications, MILORD has the advantage of less computational effort. The results of both dispersion models identified the localization of CO_2 sources mostly in the Po Valley and in the North European plains, as found by the deterministic approach, and with a contribution from SW.

Thus, while the results previously obtained using simple trajectory models are overall confirmed, the importance of using advanced models is addressed, since they provide a better detailed and more physical description of the variability of the dispersion processes, related to the intrinsic stochastic nature of the atmosphere. When quantitative assessment of the pollution in highly complex sites, like the Alps, is needed, the use of meteorological model and Lagrangian particle dispersion model become essential to properly trace, study and evaluate the effect of this kind of peak events and to identify the source areas.

REFERENCES

Apadula F., Gotti A., Pigini A., Longhetto A., Rocchetti F., Cassardo C., Ferrarese S., Forza R., 2003: Localization of source and sink regions of carbon dioxide through the method of the synoptic air trajectory statistic. *Atmospheric Environment,* **37**, 3757-3770.

Boetti M., Trini Castelli S., Ferrero E., 2017. Reviving MILORD long-range model for simulating the dispersion of the release during Fukushima nuclear power plant accident. Chapter 62 in Air Pollution Modeling and its Application XXV, C. Mensink and G. Kallos (eds.) Springer Proceedings in Complexity, Springer International Publishing Switzerland, 387-391

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

Ferrarese S., Apadula F., Bertiglia F., Cassardo C., Ferrero A., Fialdini L., Francone C., Heltai D., Lanza A., Longhetto A., Manfrin M., Richiardone R., Vannini C., 2015: Inspection of high-concentration CO2 events at the Plateau Rosa Alpine station, *Atmospheric Pollution Research*, **6**, 415-427

Skamarock W.C., Klemp J.B., Dudhia J., Gill D.O., Barker D.M., Duda M.G., Huang X., Wang W., Powers J.G., 2008: A Description of the Advanced Reserach WRF Version 3, NCAR Techical Note, Boulder, USA, 125 pp.

Trini Castelli S., 2012: MILORD - reload. Model for the Investigation of Long Range Dispersion. Internal Report ISAC-TO/02-2012, 10 September 2012, 28 pp.

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.