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Detection of CO_2 source areas using two Lagrangian particle dispersion models, at regional scale and long range

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Fisica Torino

Everything started from the trajectories….

A short history

In order to study and reproduce the long-range and transnational transport of atmospheric pollutants, the first (numerical) models were based on trajectories

The trajectory model:

The displacement of the particle is ***deterministic*** and it is determined by the ***transport*** due to the ***mean wind***.
Trajectory of ''***a specific infinitesimally small air parcel*** ***"*** is computed integrating the ***trajectory equation***

$$\Delta x_i = v_i \, \Delta t \;\; , \;\; i = 1, 2, 3$$

TRAIETN (IFS) **: TR**i-dimensional **A**tmospheric **I**nterpolation **E**valuation of **T**rajectory

- Trajectory model developed at the Department of Physics, University of Turin.

A short history

Next developments, starting from TRAIETN: a Lagrangian particle dispersion model

- Pollutant release: a ***large number*** of ***numerical particles*** are released in $P(x_0, y_0, z_0; t_0)$
- Each particle has
  - ➢ a negligible volume;
  - ➢ a specific pollutant mass (***conserved***);
- The trajectories of particles do not interact with each other: ***one-particle*** **model**

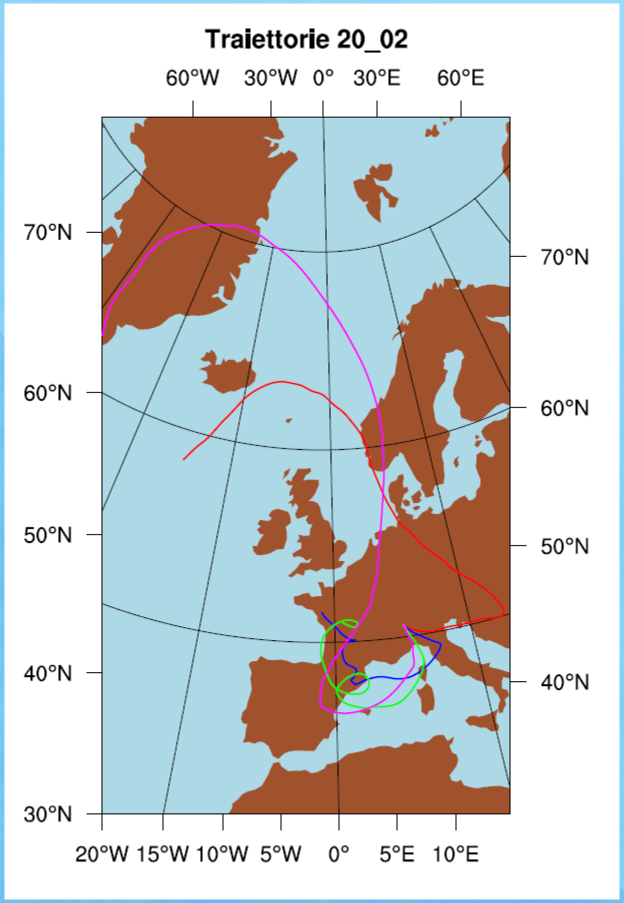
Particle
- ***transport*** : deterministic term, local mean wind, $\overline{U}$
- ***diffusion*** : stochastic term, turbulence (wind velocity fluctuations), u

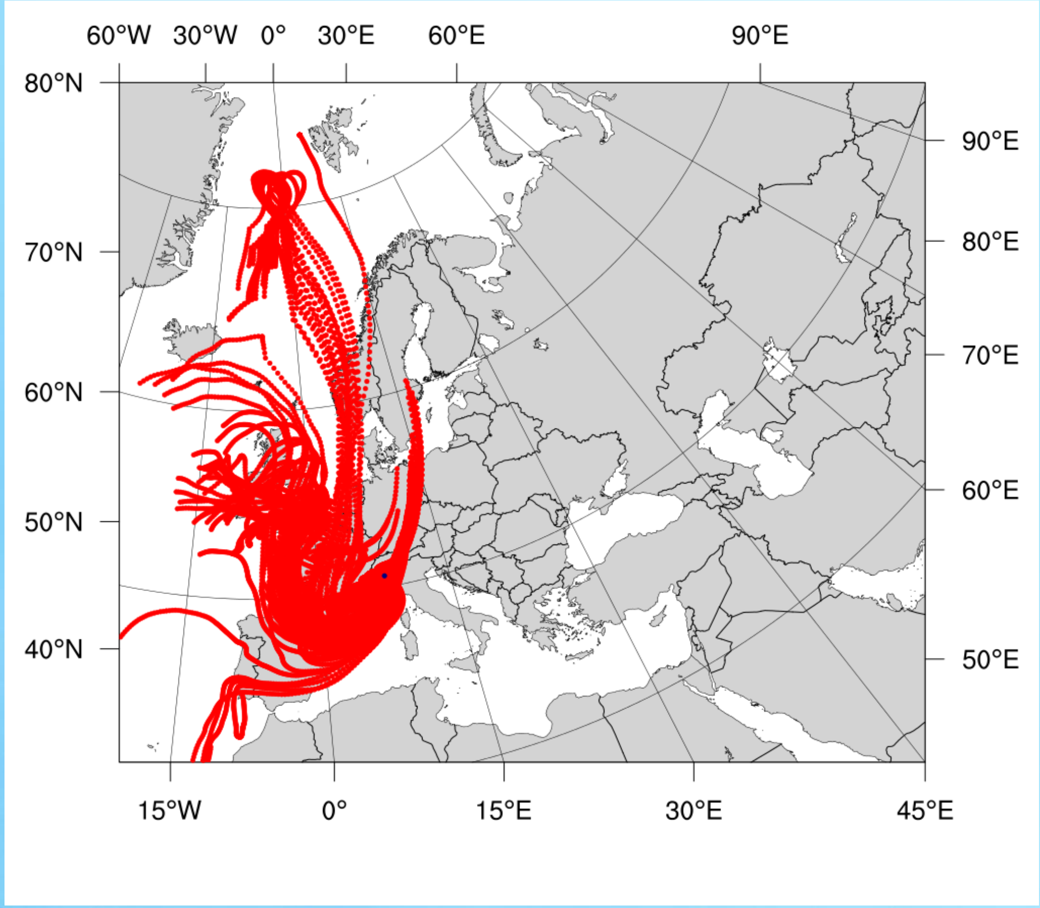
….plus depletion, transformation, deposition etc….

MILORD: Model for the **I**nvestigation of **LO**ng **R**ange **D**ispersion

➢ LPDM developed at the (ex) Institute of Cosmo-Geophysics, now Institute of Atmospheric Sciences and Climate, CNR.

Example: TRAIETN vs MILORD (1 part per Δt)





The rationale and goal

CO_2 concentration in 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 environment and they are suitable to measure background concentration of greenhouse gases.

At remote sites the CO_2 concentration peaks can be related to transport on long-range scale: extreme events of very high concentration can be useful for the localization of source areas.

The case study

Plateau Rosa station is a synoptic meteorological station operating since 1953.

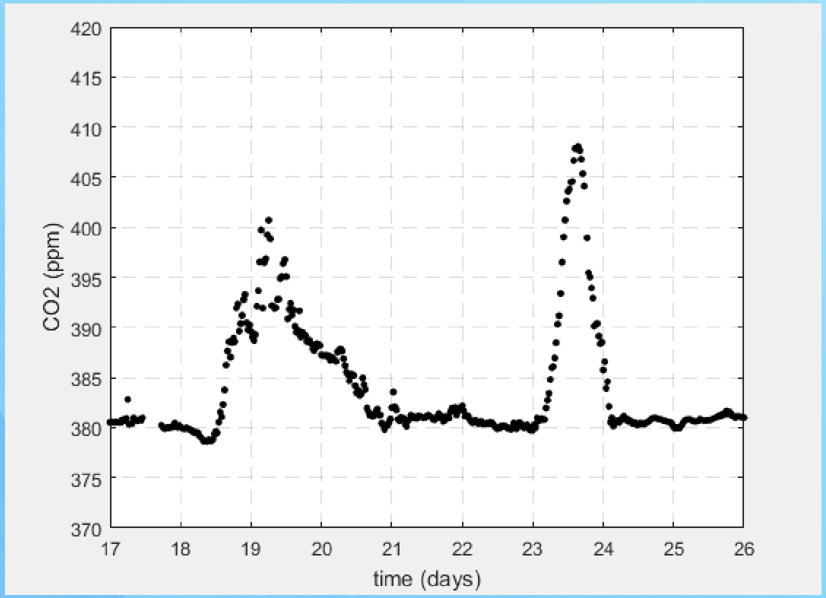
Geographical coordinates : 45.93° N , 7.71° E, 3480 m a.s.l. .

Gases like CO_2 are regularly measured at the station.

The station collects CO_2 concentration since 1989.

Thanks to its position and altitude it is suitable for the background measurement of greenhouse gases.

The case study and the past work

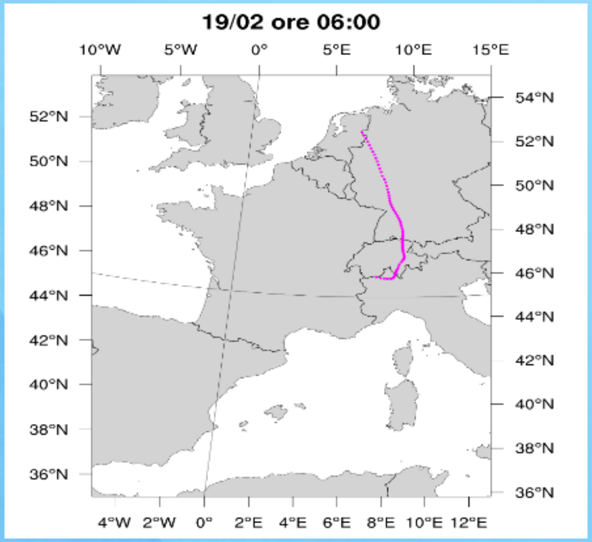


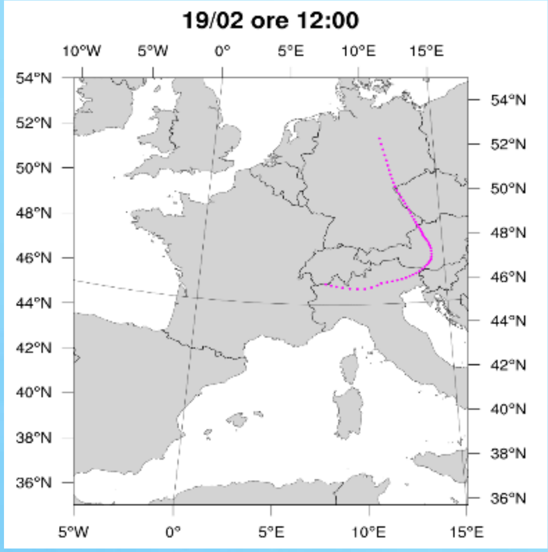
CO_2 concentrations (ppm) from 17 to 26 February 2004 measured at Plateau Rosa

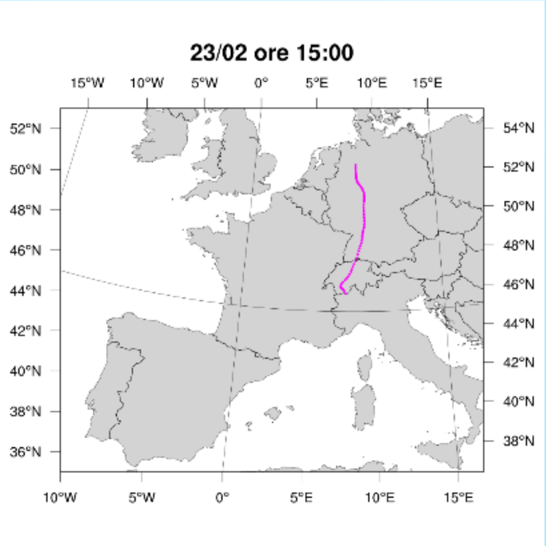
- Background concentration value : **380 ppm**
- First peak event
  - 18 February 2004 at 22:00 UTC
  - 19 February 2004 at 06:00 UTC (max value = **401 ppm**)
  - 19 February 2004 at 12:00 UTC
- Second peak event
  - 23 February 2004 at 15:30 UTC (max value = **408 ppm**)

Plateau Rosa is a background station: as such, extremely high or extremely low CO_2 concentration values are usually expunged for the computation of background data.
However, peaks of CO_2 concentration (as in February 2004) can be interestingly investigated to localize short or long distance sources from which the CO_2 is transported to the site.

The case study and the past work







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, to study the evolution of the meteorological fields and to identify the deterministic trajectories of the polluted air masses during the occurrence of CO_2 peaks.

The case study and the present work

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.

Regional scale: FLEXPART-WRF, FLEXible **PART**icle dispersion model

FLEXPART was set in backward mode, driven WRF simulated meteorological fields, from simulations where the ECMWF analyses are used as input.

Long-range: MILORD, Model for the **I**nvestigation of **LO**ng **R**ange **D**ispersion

MILORD was driven directly by the ECMWF analyses. MILORD was run for the first time in the backward-mode, after some preliminary sensitivity analysis.

The (qualitative) comparison

The meteorological input

ECMWF (European Centre For Medium Range Weather Forecasts) **analyses**

Latitude ranges from 15° N to 80°N

Longitude ranges from 60°W to 45° E

Horizontal resolution: 0.5° x 0.5°

11 pressure levels

Timeframe frequency : 6 hours

WRF (Weather Research and Forecasting)

Two nested domains D1 , D2

Horizontal resolution:

26 km (D1) , 8 km (D2)

28 vertical levels

Output time interval : 3 hours

WRF domains

The (qualitative) comparison

SIMULATIONS SETUP

MILORD

- *Input:* 6 hours ECMWF analyses
- *Box of receptor volume*
  - Centered on geographical coordinates of Plateau Rosa , 3480 m a.s.l.
  - horizontal domain 0.01° x 0.01°,
  - vertical layer from 650 to 600 hPa
- *Constant timestep :* 2160 s
- 100 particles at each timestep
- *Period of simulation*

First event: from 20/02 at 21:00 back to 18/02 at 13:00 UTC

Second event: from 24/02 at 03:00 back to 23/02 at 03:00 UTC

FLEXPART-WRF

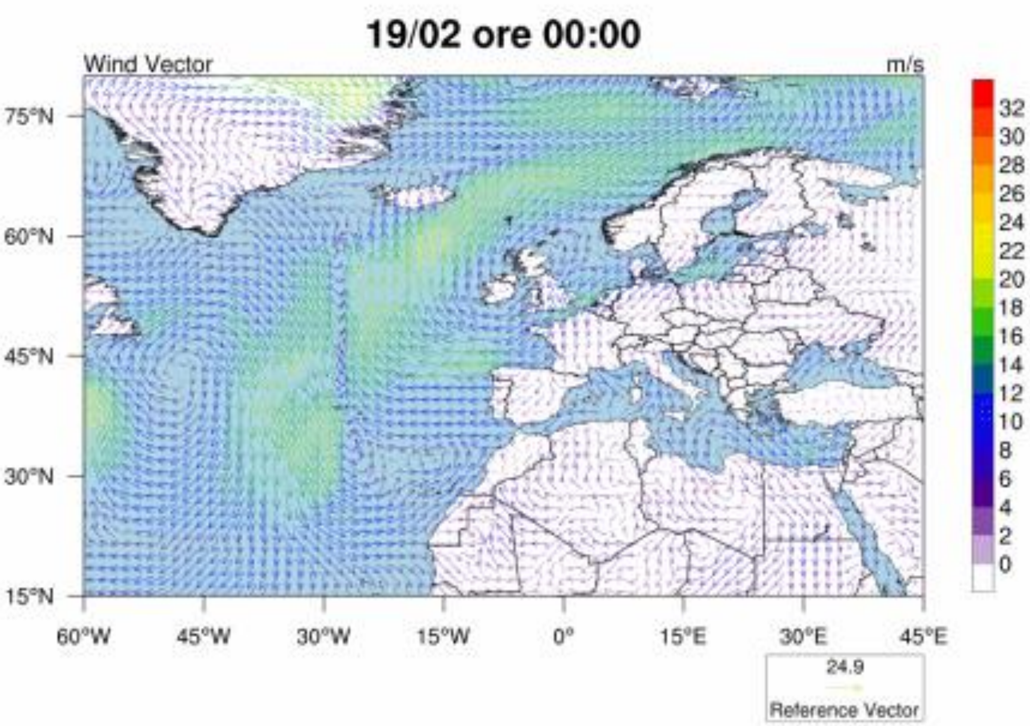
- *Input:* 3 hours WRF wind fields
- *Box of receptor volume*
  - geographical coordinates of Plateau Rosa , 3480 m a.s.l.
  - one layer of release
  - vertical layer from 680 to 600 hPa
- *Variable timestep*
- Total particles released: 100000
- *Period of simulation*

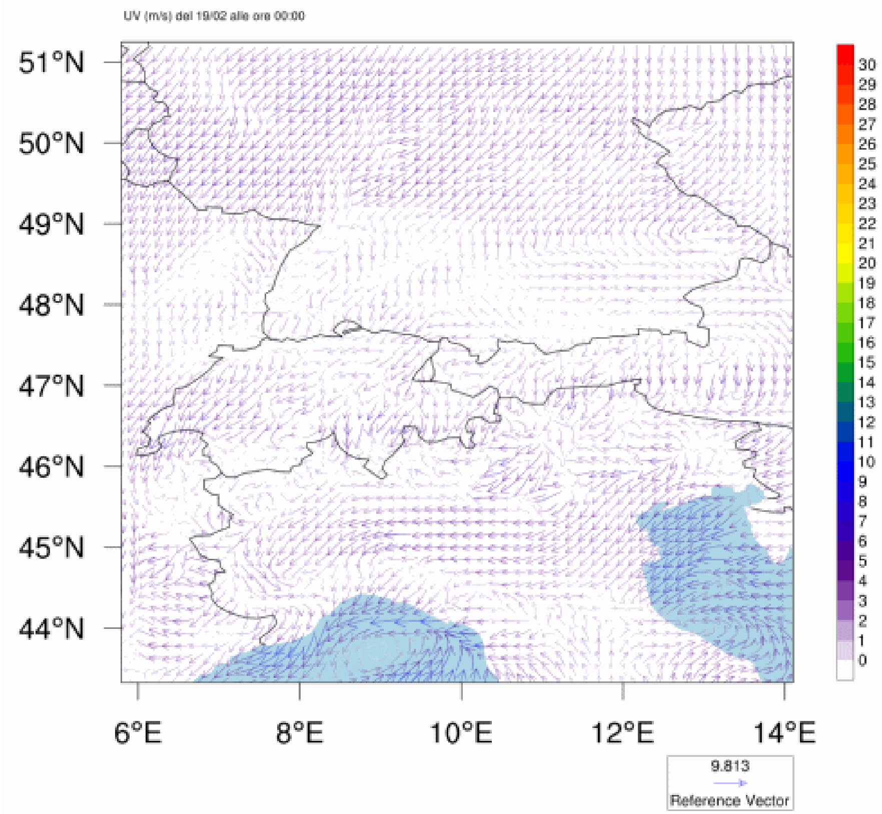
First event: from 20/02 at 21:00 back to 18/02 at 13:00 UTC

Second event: from 24/02 at 03:00 back to 23/02 at 03:00 UTC

The (qualitative) comparison – wind fields 18-24/02 6-h

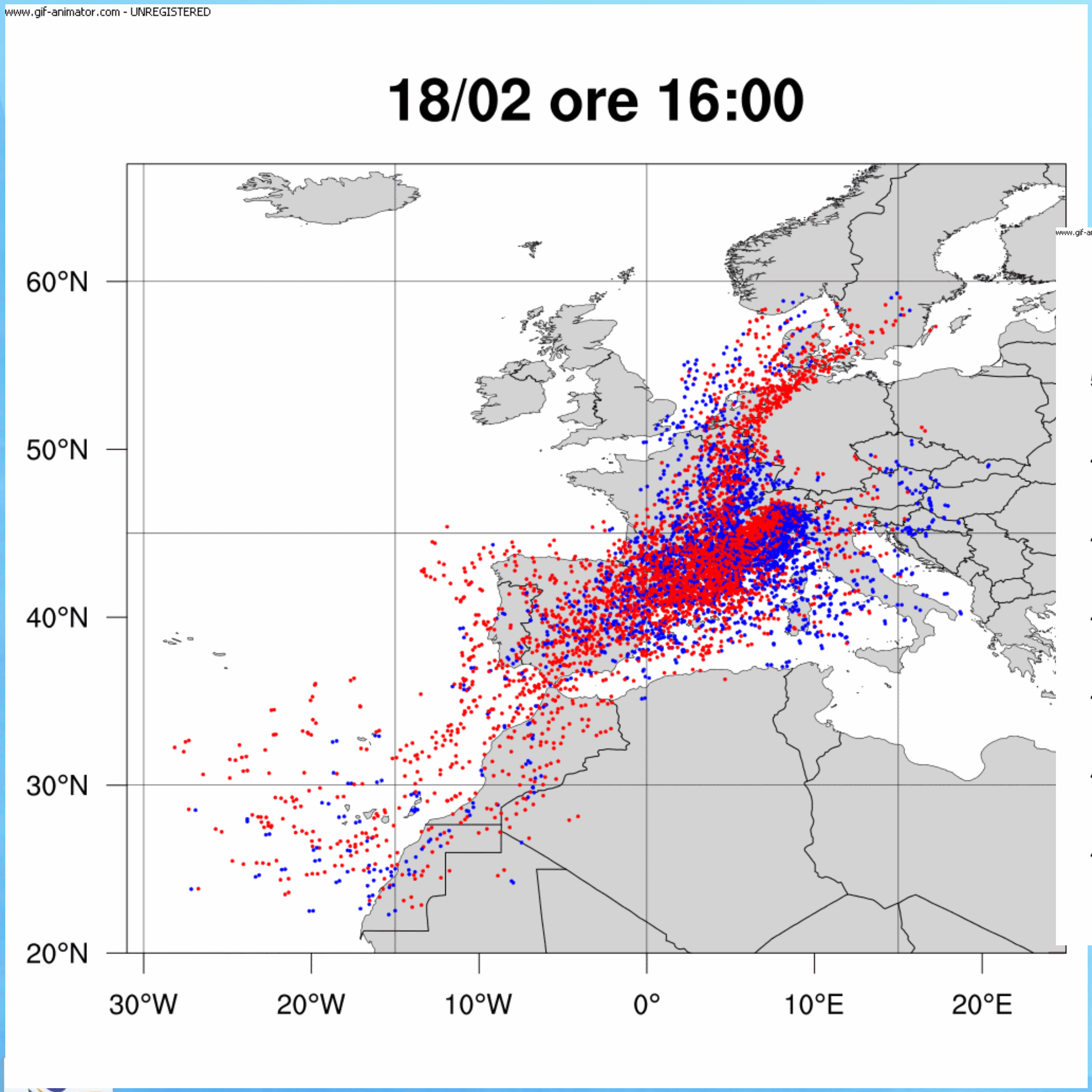
WIND FIELDS: ECMWF (1000 hPa) – WRF (10 m)

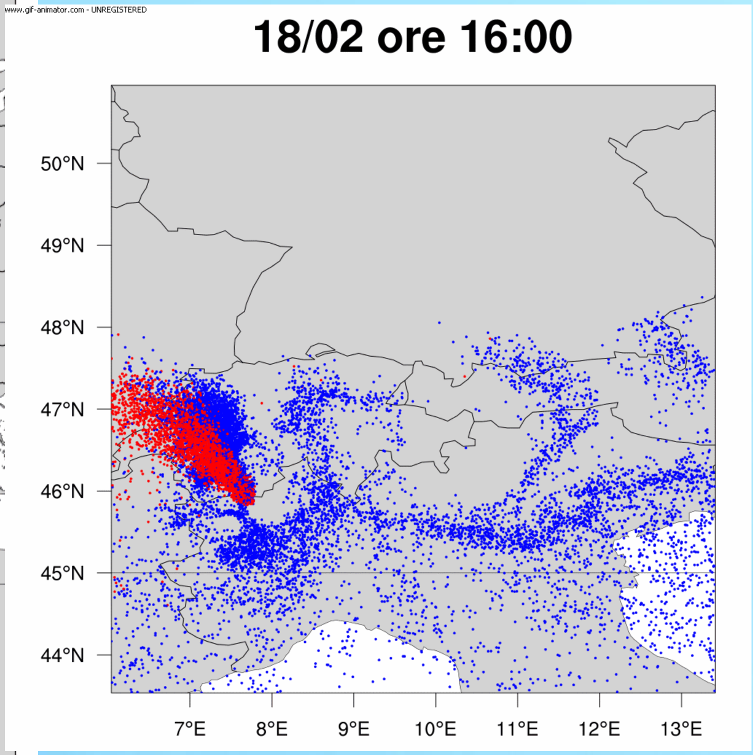




The (qualitative) comparison – first event

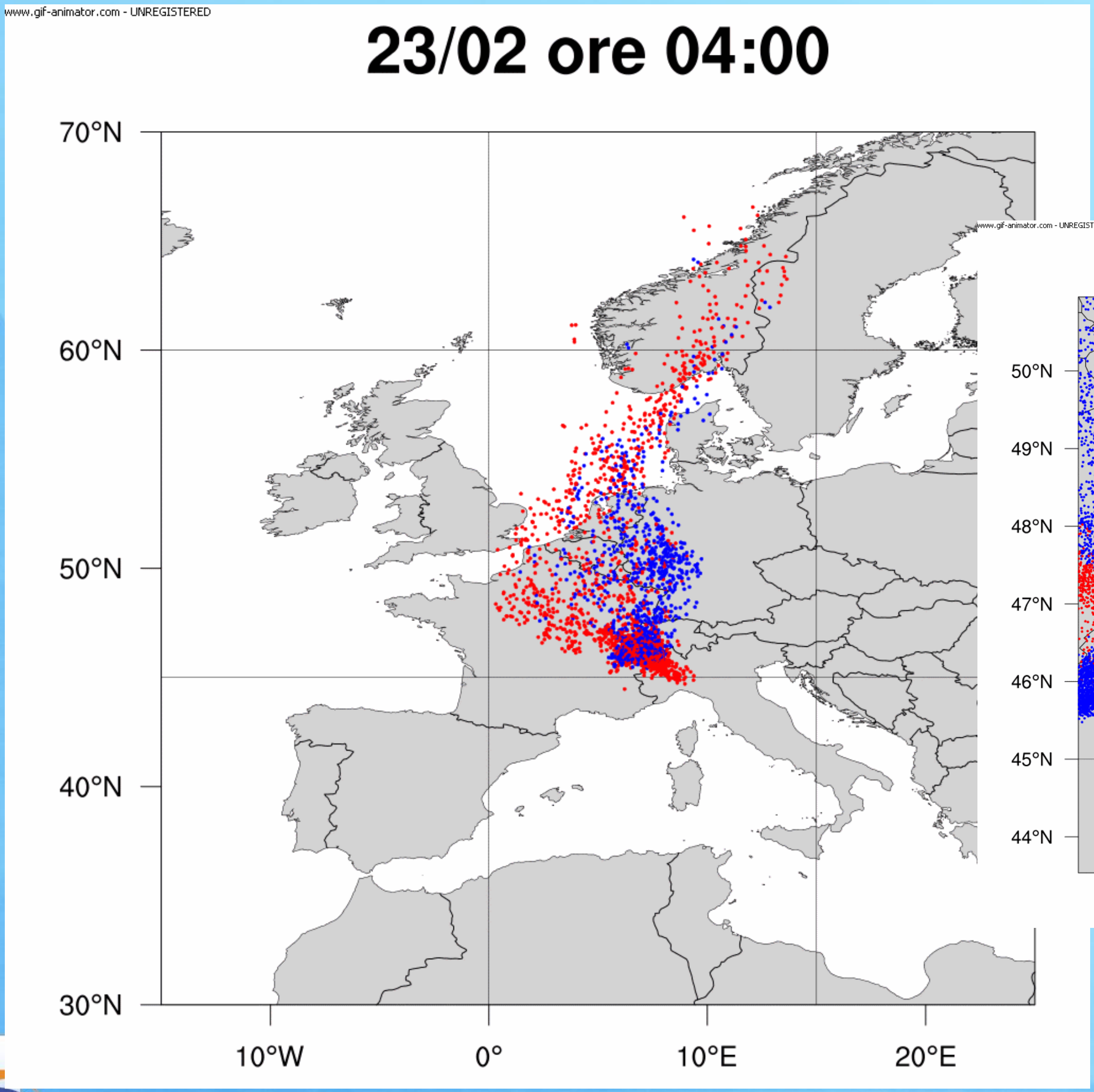
MILORD (Large scale) **FLEXPART - WRF (Regional scale)**

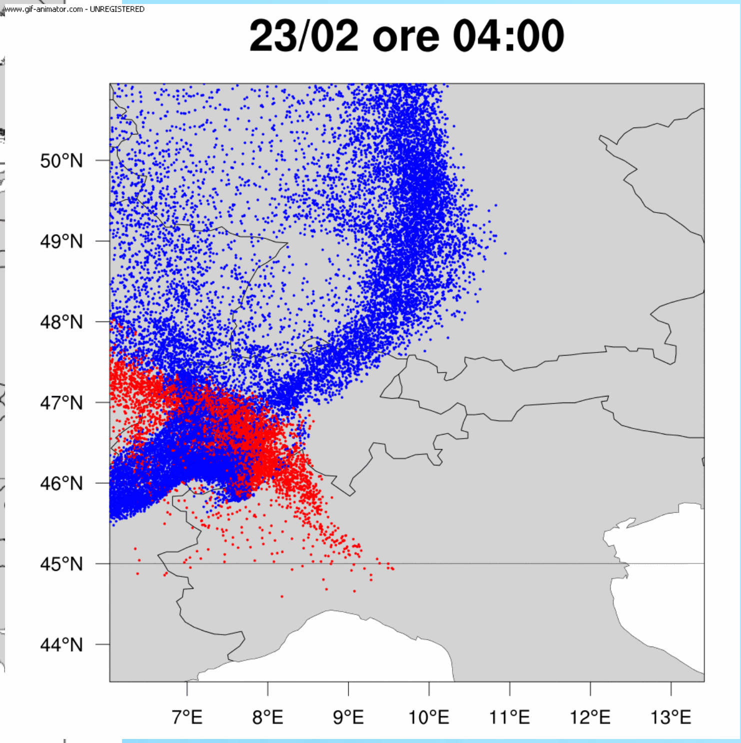




The (qualitative) comparison – first event

MILORD (Large scale) **FLEXPART - WRF (Regional scale)**





Discussion 1/2

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.

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.

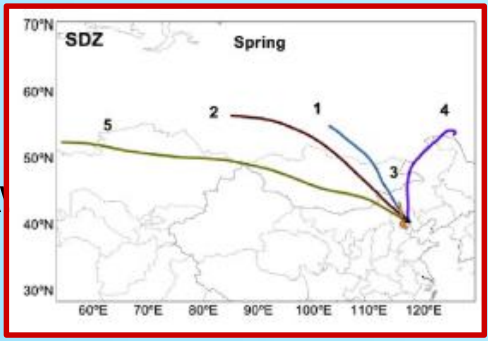
In practical applications, MILORD has the advantage of less computational effort.

Discussion 2/2

Trajectory models keep nowadays to be applied:

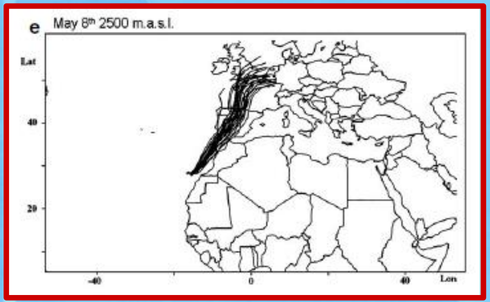
Trajectories -> cluster analysis application in seasonal periods

Liu L. et al., **2018**, Analysis of patterns in the concentrations of atmospheric greenhouse gases measured in two typical urban clusters in China, Atmos. Environ. 175, 343-345



Fang S.X., **2017** Study of atmospheric CO_2 and CH_4 at Longfengshan WMO/GAW regional station: The variations, trends, influence of local sources/sinks, and transport Science China Earth Science 60, 1886-1895

CASE STUDY: McClure et al., **2016**, Carbon dioxide in the free toposphere and boundary layer at the Mt.Bachelor observatory, Aerosol Air Qual. Res 16, 717-728

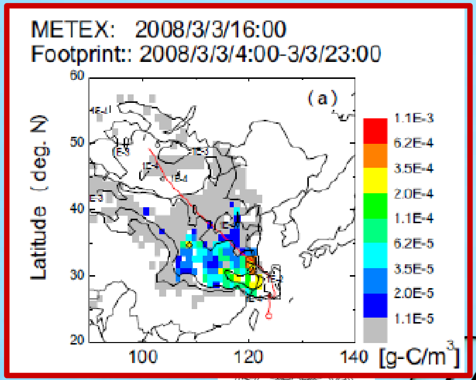


Ensemble back trajectories during events, source-receptor analysis

Izquierdo R. et al., **2011**, Source areas and long-range transport of pollen from continantal land to Tenerife (Canary Islands), Int. J. Biometerol 55, 67-85

Trajectories, FLEXPART

Minejima C., **2012** Analysis of $\Delta O_2/\Delta CO_2$ ratios for the pollution events observed at Hateruma Island, Japan, Atmos. Chem. Phys. 12, 2713-2723



Conclusions

The results previously obtained using simple trajectory models are overall confirmed.

At the same time, 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 advanced modelling systems, like meteorological and Lagrangian particle dispersion models, become essential to properly trace, study and evaluate the effect of this kind of peak events and to identify the source areas.

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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.

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