Applications of backtrajectory analyses at the Alpine site of Aosta, Italy

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1. Introduction

The Aosta Valley is an Italian region (130,000 inhabitants) located at the border between Italy, France and Switzerland, in the north-western Alps, its average altitude being >2000 m a.s.l. (Fig. 1).

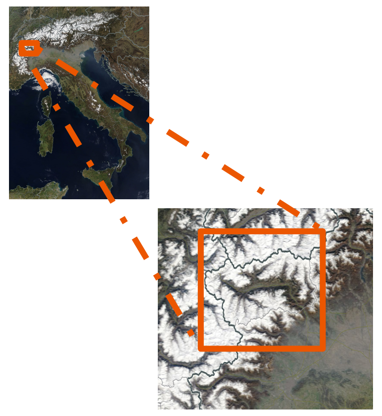

Figure 1. Italy and zoom over the Aosta Valley.

The area is generally pristine, with only few urban settlements (Fig. 2). Pollutant concentrations are on average very low (e.g., yearly mean PM_{10} concentrations <20 µg m^{-3}), which makes the contribution of pollution transport – and hence, the analysis of backtrajectories – particularly relevant (PM_{10} can reach peak concentrations >100 µg m^{-3} in these cases, cf. Section 3).

Figure 2. Matterhorn, one of the most popular mountains in the Aosta Valley together with Mt. Blanc.

Being a "crossing point" between continental Europe and the Mediterranean basin, the Aosta Valley is affected by transport from multiple regions:

- the neighbouring Po Valley, a largely populated and industrialised area (large cities such as Turin and Milan are located there). This is mainly a source of anthropogenic pollution, such as fine particulate matter;
- the Sahara desert, a strong source of mineral dust.

2. Ground-based Measurements

A ground-based network of instruments is distributed over the investigated area to capture the spatial and temporal variations of the pollutants. It consists of:

- instruments for *in-situ* measurements (Fig. 3), e.g. air pollutant concentrations (PM, NO_x, O_3, etc.) and meteorological data. Chemical analyses (water-soluble ions, metals, elemental/organic carbon) are furthermore performed on the collected aerosol samples;
- sun (spectro-)photometers for column-integrated retrievals (e.g., aerosol properties, Fig. 4);
- an Advanced Lidar Ceilometer (ALC, Fig. 4) for the estimation of the vertically-resolved aerosol load (backscatter profile).

Figure 3. One of the measuring stations of the air quality network in the Aosta Valley.

Figure 4. The Advanced Lidar Ceilometer (left) and the aerosol sun photometer (right).

The instrumental network allows to detect any particular episode (together with its starting/ending time and spatial/vertical extent) that should be further investigated by backtrajectory analyses.

3. Applications

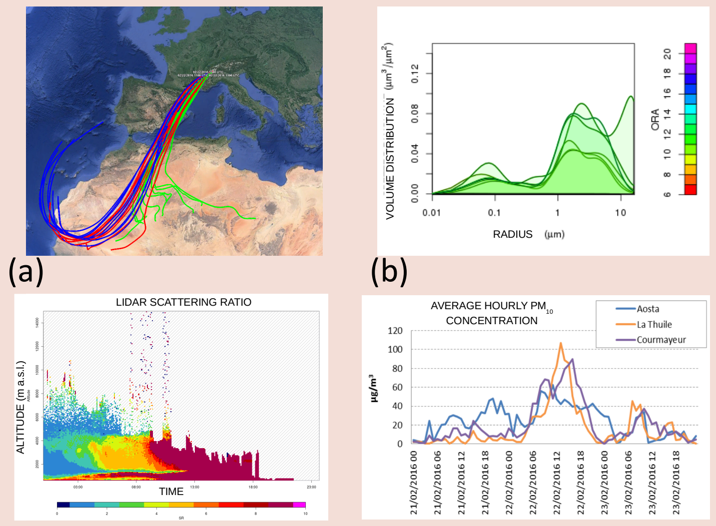

Figure 5. Backtrajectories (a), particle size distribution from the sun photometer (b), scattering ratio from the ALC (c) and surface PM_{10} concentration at multiple stations (d) on February, 22[nd] 2016.

Example 1. On January, 22[nd] 2016 air masses from the Sahara desert carried mineral dust to the Aosta Valley (Fig. 5a). The aerosol size distribution from the sun photometer evidences presence of large particles (Fig. 5b). The ALC shows that a thick, elevated layer appears in the sky (Fig. 5c). When the surface mixing layer height reaches the temperature inversion, diffusion to the lower layers occurs, and the PM_{10} concentration at the surface increases to 100 µg m^{-3} even in remote locations (Fig. 5d).

Mineral dust accounts for more than 20% on average of the PM_{10} mass measured in Aosta.

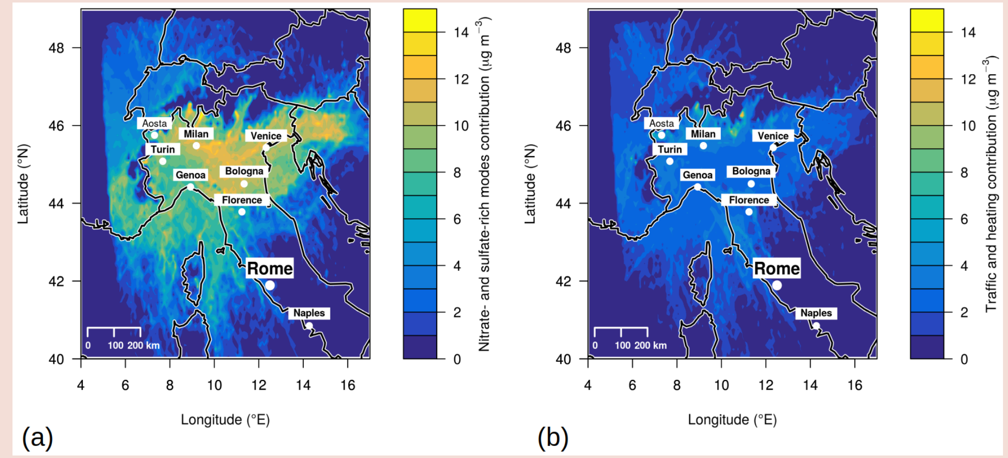

Figure 6. Concentration field trajectory statistical model using the results of chemical analyses on aerosol samples for particles originating from secondary processes (a) and combustion (b).

Example 2. Long-term backtrajectories analyses allow to assess the most likely sources on a statistical basis. Figure 6 shows the output of a Concentration Field (CF) model where trajectories are "weighted" by the aerosol mass concentration at the receptor (Aosta). Chemical speciation further allows us to partition between, e.g., secondary aerosol (Fig. 6a) mostly transported from the Po basin (yellow area) and primary aerosol from combustion (Fig. 6b) of more local origin. Taken from Diémoz et al., ACP, 2019.

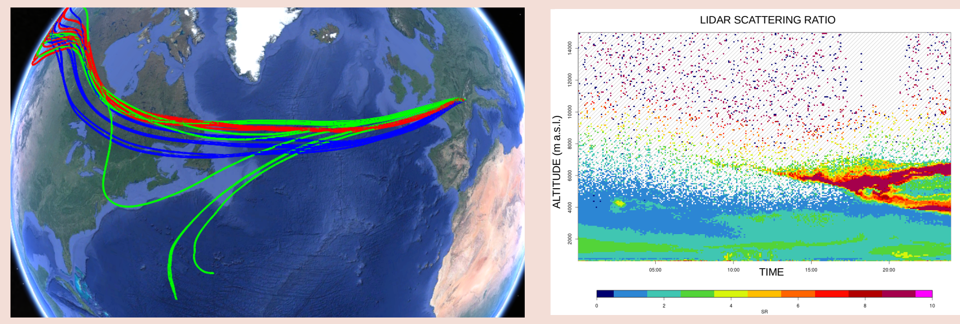

Figure 7. (a) Backtrajectories showing transport from British Columbia and (b) scattering ratio from ALC revealing the arrival of the smoke over Aosta, August, 27[th] 2018.

Example 3. Upward currents in pyrocumulonimbus clouds and strong horizontal winds allows large-scale transport of smoke over thousands of km (Fig. 7a). This is the case of August 2018, when smoke from fires in California (USA) and British Columbia (Canada) was clearly detected over the Aosta Valley (Fig. 7b).

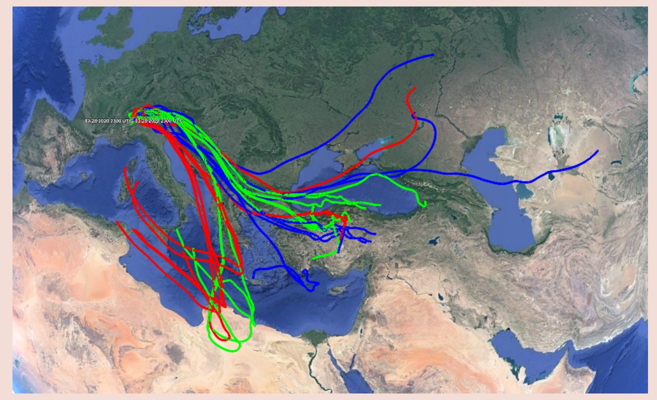

Figure 8. Transport of mineral dust from the Caspian lowlands, March, 28[th] 2020.

Example 4. On March 28th, 2020, transport of mineral dust from the Caspian lowlands occurred. This is an unusual event, since mineral dust in southern Europe mostly arrives from the Sahara desert. Peak PM_{10} concentrations of 55 µg m^{-3} were measured in Aosta, however daily averages as high as 150 µg m^{-3} (i.e. three times higher than the EU air quality standard for PM_{10}) were observed in other Italian regions.

4. Chemical Transport Models

A three-dimensional Eulerian chemical transport model (FARM, Flexible Air quality Regional Model) is used to simulate the transport, chemical conversion, and deposition of atmospheric pollutants on a 1-km resolution grid. This allows to interpret and complement the experimental observations and the Lagrangian approach of the backtrajectory models.

A numerical weather prediction model (COSMO) is employed to drive FARM. A regional emission inventory must be also supplied to accurately assess the magnitude of the pollutant loads and their variability in both time and space.

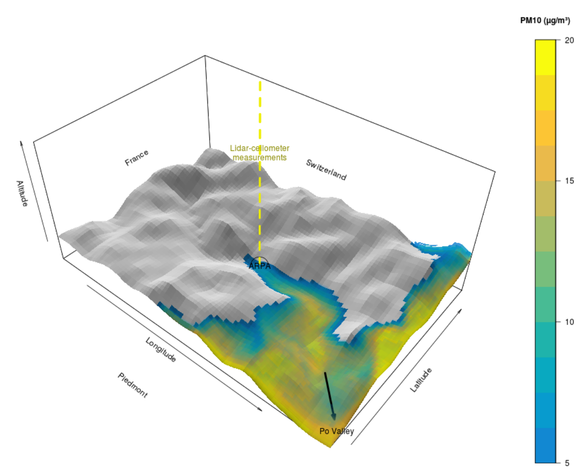

Figure 9. 3-D simulation of PM_{10} concentration by FARM (image from 28 August 2015 at 15:00 UTC). The image clearly shows the entrance of the aerosol-rich air mass from the Po basin into the Aosta Valley (yellow–blue area).

5. References

The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the READY website (https://www.ready.noaa.gov).

This was employed in the following publication:

- Diémoz, H. et al.: One Year of Measurements with a POM-02 Sky Radiometer at an Alpine EuroSkyRad Station, Journal of the Meteorological Society of Japan, 2014, doi:10.2151/jmsj.2014-A01

Backtrajectories calculations (from other models) were also used in the following works:

- Diémoz, H. et al.: Transport of Po Valley aerosol pollution to the northwestern Alps – Part 1: Phenomenology, Atmos. Chem. Phys., 19, 3065-3095, https://doi.org/10.5194/acp-19-3065-2019, 2019
- Diémoz, H. et al.: Transport of Po Valley aerosol pollution to the northwestern Alps – Part 2: Long-term impact on air quality, Atmos. Chem. Phys., 19, 10129–10160, https://doi.org/10.5194/acp-19-10129-2019, 2019