An overview of the air quality in the Pyrenees and its relationship with heat waves

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Introduction

While urban environments often receive the most attention in air quality research, rural and mountainous regions must not be overlooked. The **Pyrenees mountain range** in southwestern Europe forms a natural border between Spain and France, extending approximately 430 kilometers from the Bay of Biscay in the west to the Mediterranean Sea in the east. In the Pyrenees there are only a few ground sensors which give information air pollutant concentrations although high pollution episodes can occur. In **winter** stagnant conditions can lead to high **NO_2 concentrations** in populated valleys, while in **summer O_3** generated in urban and industrial areas or formed in rural areas can be transported through local or mesoscale circulations and increased with the presence of Volatile Organic Compounds (VOCs).

Objectives of the study

- To explore the **spatial and temporal overview** of the **O_3** pollutant concentrations and **NO_2** vertical column densities.
- To analyze the ozone concentrations and **threshold exceedances** in the Pyrenees.
- To relate **heat wave** periods with **ozone** concentrations.

Methods for ozone (O_3)

The ozone formation and accumulation is particularly relevant during **summer**, when there is enough solar irradiance and when high temperatures intensify photochemical reactions. Thus, it is a critical pollutant in the context of climate change.
There are 24 air quality monitoring stations (20 for ozone) from 2019 to 2023 (Fig. 1) distributed over 6 areas:

- Andorra (2)
- Catalonia (8)
- Navarra (4)
- Basque Country (4)
- Aragon (1)
- France (1)

Heat wave detection criteria

Air temperature at 2 m from ERA5 reanalysis has been used for the area (42.5° to 42.75° N and -1° to 2.5° E) selecting the days when 99th percentile of the daily maximum temperature (1981-2023) was exceeded for **3 days or more** (Xu et al. 2016).

Methods for nitrogen dioxide (NO_2)

The Tropospheric Monitoring Instrument (TROPOMI), onboard the Sentinel-5 Precursor (**Sentinel-5P**) satellite, monitors tropospheric nitrogen dioxide (NO_2) by measuring its vertical column density (VCD)—the total number of NO_2 molecules in a column of air from the Earth's surface to the top of the troposphere. We use data from May 2018 to December 2023 (Campos et al. 2024).

Ozone concentrations from air quality stations

Fig. 1. Location of 24 air quality stations in the Pyrenees and limit of the Pyrenees region defined by the *Observatorio Pirenaico de Cambio Climático* (OPCC).

- Ozone mean concentrations are highest in **Montsec** which° is a **rural** remote station
- Escaldes-Engordany in the Central valley of Andorra has the lowest mean ozone concentration (Fig. 2) -> **urban** location (high NO and NO_2 emissions).
- Hourly information threshold limit (180 $\mu g/m^3$) was exceeded at some point in places such as Bellver, Berga, Montsec, Torrelisa and Lourdes.

Stations	Urbanization type	Mean O_3 ($\mu g/m^3$)	Max O_3 ($\mu g/m^3$)
Engolasters	Rural	**91.64**	163.6
Escaldes-Engordany	Urban	67.74	144.8
Agullana	Rural	87.91	163.0
Bellver	Rural	87.05	**205.0**
Berga	Suburban	82.55	**194.0**
Montsec	Rural	**103.16**	**182.0**
Pardines	Rural	**91.49**	173.0
Ponts	Rural	88.84	167.0
SantaPau	Rural	81.82	159.0
Sort	Rural	82.86	143.0
Torrelisa	Rural	**92.53**	**215.0**
Alsasua	Rural	80.85	156.0
Iturrama	Urban	71.03	138.0
Leitza	Rural	78.79	159.0
Sangüesa	Urban	78.22	147.0
Agurain	Urban	85.73	162.0
Pagoeta	Rural	85.10	169.0
Urkiola	Rural	**89.94**	168.0
Zumarraga	Urban	79.38	149.0
Lourdes	Urban	80.96	**180.0**

- Highest maximum values in **Torrelisa** and **Bellver** (Fig. 2): rural locations that are affected by transport of ozone or precursors from urbanized areas nearby where ozone formation may be enhanced due to the presence of VOCs.

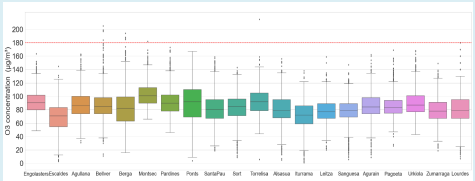


Fig. 2. Boxplots of the daily maximum ozone concentration between 2019-2023 per location. The red line represents the hourly ozone information threshold (dangerous for vulnerable people).

Ozone and heat waves

- The number of heatwaves (HW) varies depending on the selected criteria. Based on ERA5 data and the **criteria** described above, a total of 17 heatwaves were identified over five years, comprising 105 heatwave days in total.

Year	HW number	HW days
2019	5	22
2020	3	13
2021	2	9
2022	4	37
2023	3	24
Total	17	105

- **Maximum ozone** averaged concentrations occurred during **heatwave** periods in June, July and August.
- **2022** included a large number of heatwaves and the largest mean ozone concentrations as well (Fig. 3).
- Strong ozone dependence on solar irradiance and **extreme** temperatures.

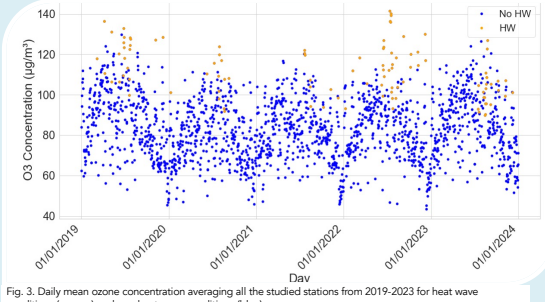
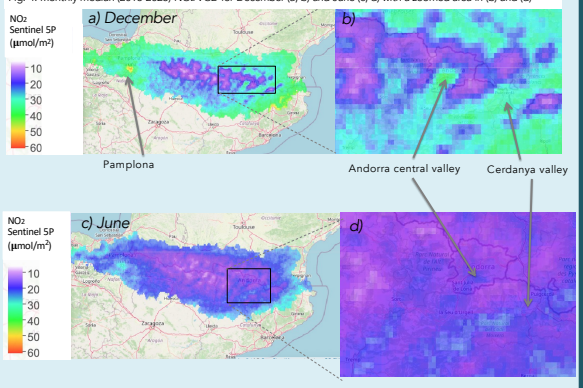


Fig. 3. Daily mean ozone concentration averaging all the studied stations from 2019-2023 for heat wave conditions (orange) and non-heat wave conditions (blue).

NO_2 spatial and temporal distribution in the Pyrenees from Sentinel-5P

Sentinel 5P can detect the average behavior of NO_2 spatial distribution through vertical column densities (VCD) and can identify specific days of high ground level NO_2 concentrations. Nevertheless, there is an important uncertainty about lost or added information in the range of values in the Pyrenees.

Fig. 4. Monthly median (2018-2023) NO2 VCD for December (a, b) and June (c, d) with a zoomed area in (b) and (d)



- Sentinel 5P can detect the **annual cycles** of NO_2.
- Median NO_2 VCD in December is higher than in June, coherent with **winter lower atmospheric dispersion**.
- High values of median NO_2 VCD in winter are located around urbanized areas (Pamplona) but relative maximums are identified in **urbanized valleys** (Fig. 4a, b): Andorra Central Valley and Cerdanya valley, although they are not observed in summer (Fig. 4c, d).

Conclusions

- Pyrenean rural stations such as Torrelisa (Aragon) and Bellver (Catalonia) reveal maximum ozone concentrations **exceeding** hourly **thresholds** while Montsec (Catalonia) shows the highest mean for the whole period.
- **Maximum ozone** averaged concentrations occur during heatwave periods.
- Sentinel 5P NO_2 vertical column densities reveal **winter** located **maximums** in certain **urbanized** Pyrenean **valleys**.

Future work

- Analyze different criteria for heat wave detection including stations, ERA-LAND.
- Explore high ozone concentration case studies linked with heat waves and the role of regional transport.

References

- Campos, C., Sola, Y., Udina, M., Bech, J., and Trapero, L.: Monitoring ground level nitrogen dioxide concentration in complex terrain areas using satellite Sentinel 5P total column observations, EMS Annual Meeting 2024, Barcelona, Spain, 1–6 Sep 2024, EMS2024-669, https://doi.org/10.5194/ems2024-669, 2024.
- Copernicus Climate Change Service, ERA 5 (2024): https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview (Accessed on May 2025)
- Xu, Z., FitzGerald, G., Guo, Y., Jalaludin, B., & Tong, S. (2016). Impact of heatwave on mortality under different heatwave definitions: a systematic review and meta-analysis. Environment international, 89, 193-203.

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