

Supplementary Material

Ozone is a secondary pollutant that is produced by a series of chemical reactions that involve nitrogen oxides (NO_x) and (VOC) volatile organic compounds as reagents in the presence of sunlight (Jenkin and Clemitshaw, 2000). The emissions of these reagents are important in urban areas where much ozone is formed. Some of it is consumed by reacting with nitric oxide and other alkyl radicals that are present in the troposphere. As the pollutants are dispersed throughout the day, the ozone that remains moves away to zones of the city that contain only small amounts of NO_x and VOCs.

1. Annual and Inter-annual O_3 Variations

The Daoudiat area receives the highest ozone concentration followed by Jef, (both of which are subjected to a clear anthropogenic impact) and, then in 2010, the Mhamid area (see Figure 1).

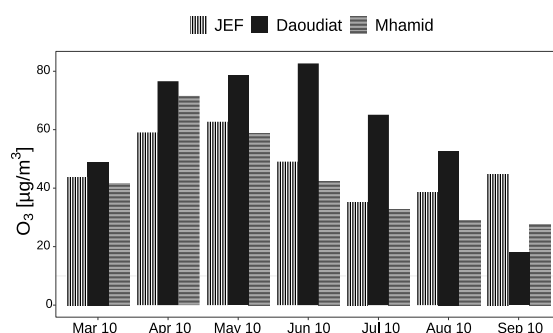


Figure 1. Average monthly O_3 levels in 2010. Stations: Mhamid, Daoudiat and Jef.

However, the average monthly ozone concentration for the year 2009 varied, with higher values in Mhamid than in Jef. The main reason for this was the opening of the motorway from Agadir to Marrakesh. In 2009, all vehicles that arrived from Casablanca (North) to Agadir (South), or vice versa, were forced to cross a large section of the city, from the north to the southwest. The high level of activity on Marrakesh roads generated significant gaseous emanations, which included NO_x and VOC, ozone precursors (Ouarzazi et al., 2003).

2. Daily and Monthly O_3 Variations

In 2009 the ozone hourly maximums reached concentration levels of 100 to 150 $\mu\text{g}/\text{m}^3$, with some isolated levels rising to 270 $\mu\text{g}/\text{m}^3$ in Mhamid. Although it is situated downstream from the city's center, the hourly averages are slightly smaller (see Figure 2). The daily average of O_3 in Mhamid was the weakest because, despite the high ozone peaks that are recorded at this station during the day, the concentration falls significantly during the night, as evidenced by the hourly averages (see Figure 2).

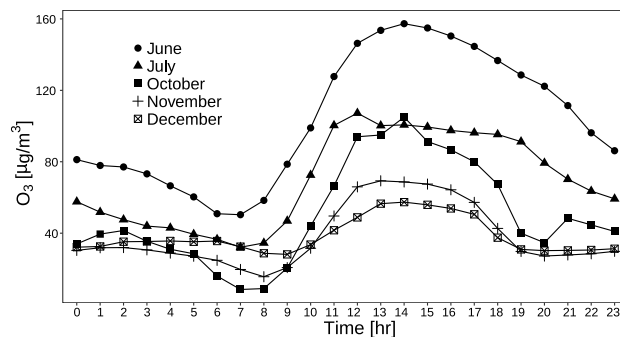


Figure 2. Hourly average of O_3 at Mhamid station in 2009.

In winter, these values reflect the level of background ozone at night. Even when the peaks are high during the day, they disappear at night. However, in spring and summer, beginning in April when the quantity of ozone produced is high, the measured values are greater during the day and still fall at night (Figure 3).

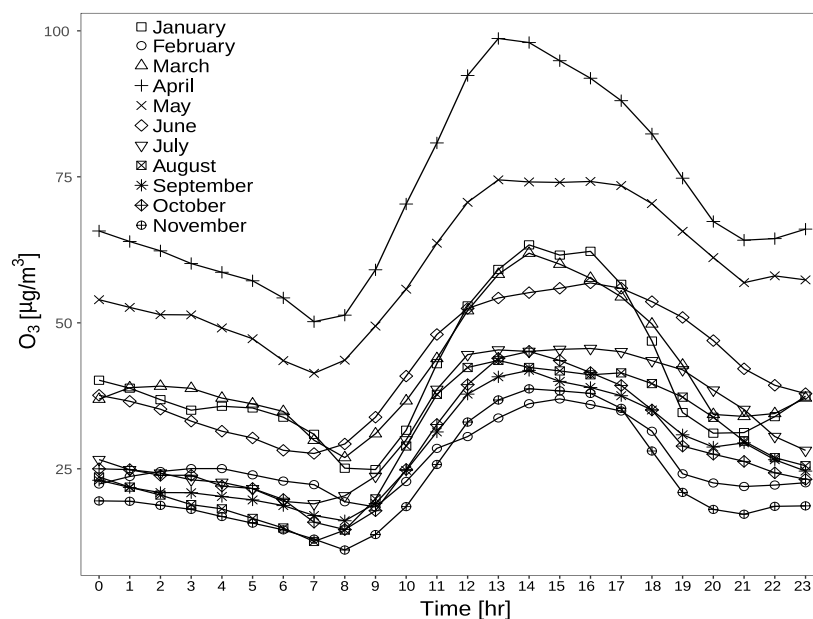


Figure 3. Hourly average of O_3 at Mhamid station in 2010.

The ozone concentration is slightly different in the Daoudiat station in 2010 (see Figure 4). The concentrations there are unusually low in July and August.

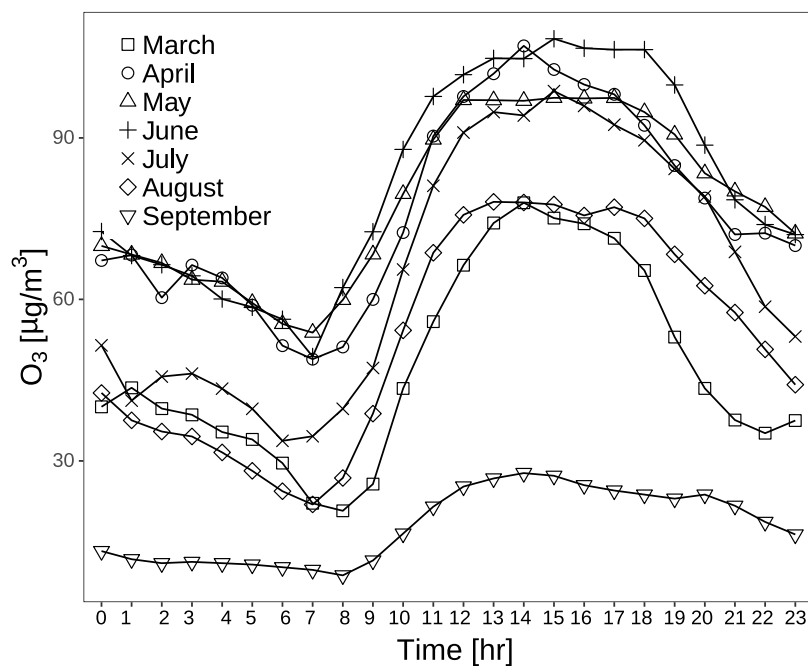


Figure 4. Hourly average of O_3 at Daoudiat station in 2010.

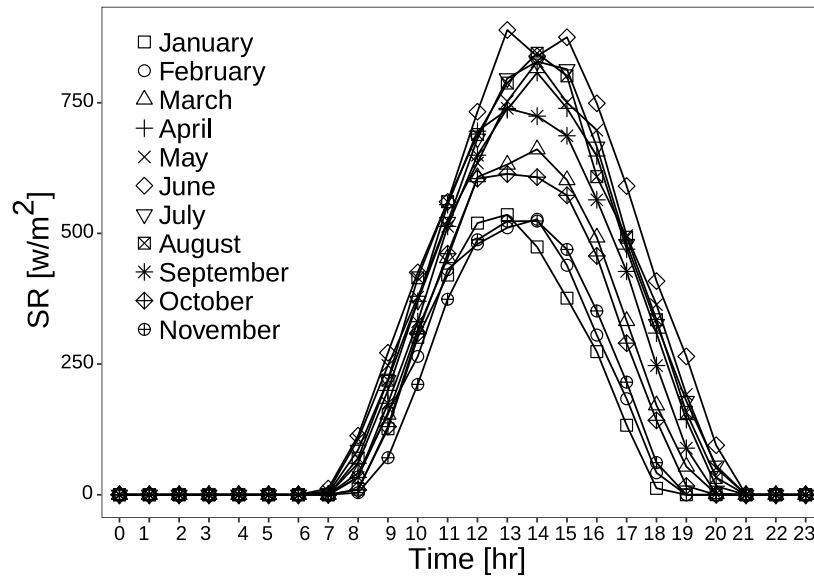
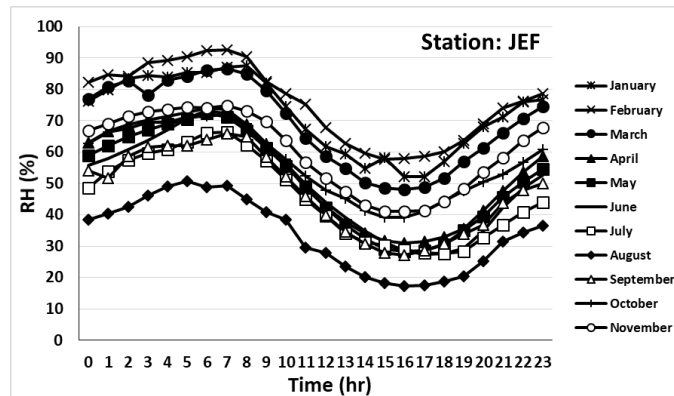
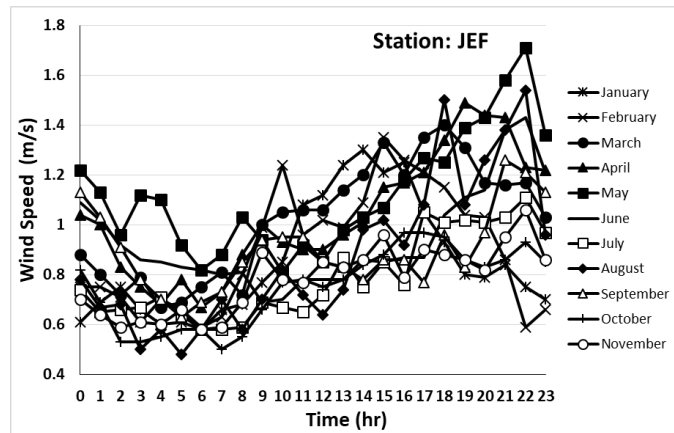


Figure 5. Solar radiation at Mhamid station in 2010.

As observed in Figure 5, the correlation of solar radiation intensity and ozone concentration is not equally strong in all seasons. The hourly average values of solar radiation are zero at night and the maximum is defined by the period of the year.



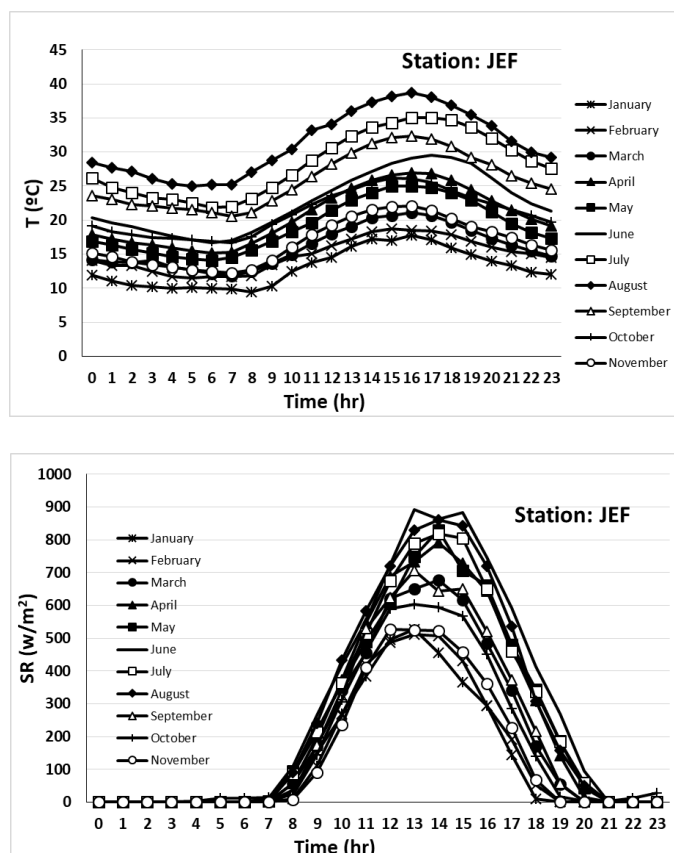


Figure 6. Meteorological parameters at JEF station in 2010.

An example of those parameters are the meteorological ones (WS, RH, T, etc.), which are depicted in Figure 6. They exhibit the behavior expected according to the relevant month.

3. 8-Hour O₃ Variations

The general trends of ozone during 2009 and 2010 are presented in Figure 7, where it becomes clear that concentrations that exceeded the legal ozone threshold occur regularly in the spring and summer, although they are often below the limits for human health.

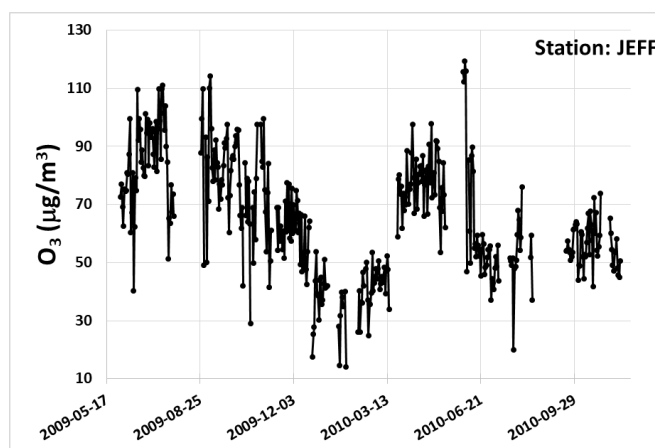


Figure 7. 8-hour O₃ average at Jef station in 2009 and 2010.

On the entire spectrum of measured values, the percentage of the average concentrations that exceed eight hours of ozone is generally highest in Daoudiat (Table 1). In this zone, the road traffic is important. The production of ozone precursors there is high and the ozone concentration exceeded the national standard during fifty days of the year in 2010.

Table 1. Percentage of 8-H Mean O₃ Concentrations as Defined in the Standard.

Station	% [O ₃] ≥ 110 µg/m ³	Maximum [µg/m ³]	Number of exceedances
Daoudiat	13.5	160	27
Mhamid	7.2	203	24
Jef	1.7	118	10

The 8-hour duration is not identical at all stations. As the Mhamid station is farthest from the city center, the duration there lasts from 1 pm until 9 pm, rather than from 10 am until 6 pm as at the two other stations.

It must be noted that the lower percentage of time during which ozone levels exceeded the standard threshold corresponds to the JEF station. However, it also occurs in a relevant number of instances at other stations (see Figure 8).

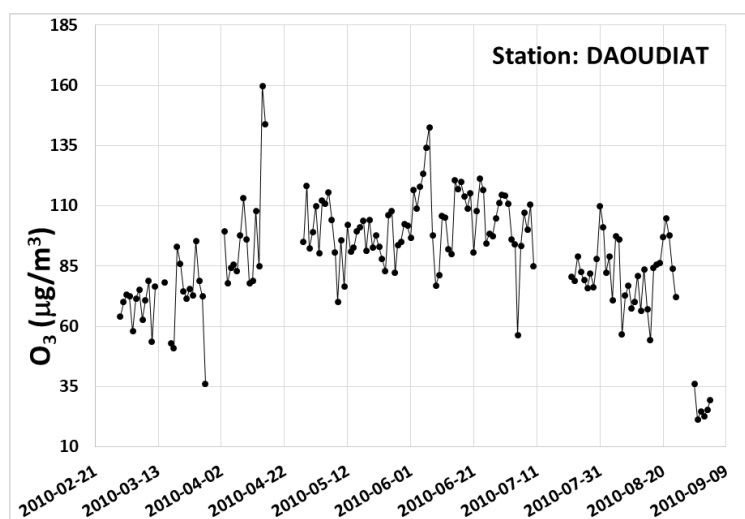


Figure 8. 8-hour O₃ average at Daoudiat station in 2010.

References

- Jenkin, M. E. and Clemitshaw, K. C. (2000), Ozone and other secondary photochemical pollutants: chemical processes governing their formation in the planetary boundary layer, *Atmos. Environ.*, 34(16), 2499-2527.
- Ouarzazi, J.;Terhzaz, M.;Abdellaoui, A.;Bouhafid, A.;Nollet, V. and Dechaux, J. -. (2003), A descriptive study of atmospheric pollutants measurement in the Marrakech conurbation, *Pollut. Atmos.*, (177), 137-151.