Evaluation of Long Range Transport of Ozone in Western Mediterranean Basin

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INTRODUCTION

Air pollution and photochemistry in the atmosphere are complicated processes that alter air quality standards in urban and remote locations. This concerns areas with complicated physiographic characteristics (rough terrain, coastal areas, vegetation variability etc). Mediterranean Region is characterised for its topographic variability (Hills and mountains) and distinct climatic characteristics (increase, decrease of the temperature respectively in summer and winter). These regional and local climatic characteristics are in favour of photochemical processes and smog formation (Jiménez et al. 2004), which is considered as the most important forms of air pollution. It appears often over urban areas as a chemical mixture of gases and particles leading to air quality problems. Photochemical smog is common in regions where certain geographic features as mountains and hills which impede air movement and weather conditions contribute to the trapping of air pollutants. The location of sources both anthropogenic and natural is in favour of multi-scale transport that is responsible for air quality problems in several locations (Benzaama et al. 2016). Most of the anthropogenic sources are located in Europe while natural ones have their origin in North Africa (desert dust) and Mediterranean Seas (sea salt, dimethyl sulphate). Ozone and aerosol formation in the Mediterranean Region is a major problem for many places not only urban. It is well known that large increase in ozone concentration tropospheric background mainly due to transport of long-range and anthropogenic emission of gases leading to ozone formation, the so-called ozone precursors (NOx, CO, CH4 and volatile organic compounds VOCs) (Gerasopoulos et al. 2006). Great consideration should be given to the problem of air pollution with ground-level ozone; sulfur-dioxide; nitrogen oxides and particulate matter (PM10) are different from other air pollutants particularly with regard to the chemical process of its production.

Millan et al. (2002) have noted that ozone concentrations in remote areas of the Mediterranean region have increased especially in summer. It is likely that this increase in original levels is due to the increase of anthropogenic emissions coming from South Europe affecting the levels of air pollution in West North African Coast (Saidi et al. 2014). In addition, the Mediterranean region is characterised by weather specification dominated by strong north wind component regardless of season. This wind flow transports the polluted air masses from Europe to North Africa across Mediterranean Sea. As it is suggested in previous studies, the synoptic and regional wind circulation during summer promotes of the transport air pollutants over long-distance (Kallos 1997). Air mass flow trajectories were previously calculated based on meteorological data (Max Planck Society for the Advancement of Science 2002), showing the
movement of pollution from Europe to the Mediterranean Region in the lowest atmosphere (2-4 km). On the other hand, the local thermal circulation and the major sources nearby the coastal zone aid to the trapping and formation of smog affecting air quality.

AIR POLLUTION TRANSPORT AND TRANSFORMATION OVER THE MEDITERRANEAN REGION

The air pollution transport and transformation was the subject of various studies during the last 20 years. Projects like SECAP and T-TRAPEM grave the first information about the re-circulation mechanisms, the layering, the paths and transformation processes, mainly the photo-oxidants (Gangoiti et al. 2001). In continuity, the International team investigates atmospheric pollution over the Mediterranean/ pollution transport into the region causes large scale decrease in air quality and precipitation (MINOS) (Max Planck Society for the Advancement of Science 2002).

Regions of Mediterranean Basin are characterised: During the cold period of the year, the washout mechanisms are important. Photochemical processes are not at their peak due to limited insolation and cloud formations. During the warm period, the wet removal processes are very limited and insolation helps photochemical processes, moreover, they affect the weather at higher latitudes (Varinou et al. 2001). The meteorology and the air masses coming towards North Africa are highly influenced by strong sea-land breeze (differencing in temperature) and the intensity of the Azores high-pressure system, which is overlooked the Western Mediterranean Basin (Milan et al. 2000).

The Algerian Coast is mainly located under the topography and climate of Mediterranean basin, surrounded by high coastal mountains and characterised by dry hot summers and mild winters. Precipitations are poor and irregular, sometimes drought. Annual average temperature is 18°C, with annual average precipitation around 450mm. Nevertheless, there is a diverse climate, with strong contrasts through the year (Hamoudi et al. 2014). The sun provides the energy to drive the winds by heating the surface of the earth and in turn the air above it (land-sea breeze during the day and sea-land breeze in the night). It is this heating that drives the in Algerian Coast most of the time.

DOMAIN OF STUDY

The domain selected is shown in Fig. 1. The horizontal resolution is 12×12 km² and 14 vertical layers were used to cover the lower troposphere with a depth starting from 50,

<table>
<thead>
<tr>
<th>Measure Station</th>
<th>(latitude=43.6 longitude= 3.88) SE</th>
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</thead>
<tbody>
<tr>
<td>SEAlgiers</td>
<td>(latitude=36.7 longitude= 2.98) NA</td>
</tr>
</tbody>
</table>

Fig. 1: Computing domain for resolution of 12*12 km (longitude*latitude).

Table 1. CAMx Specification

<table>
<thead>
<tr>
<th>Specs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>CAMx v5.2</td>
</tr>
<tr>
<td>OS/compiler</td>
<td>Linux, Ifort</td>
</tr>
<tr>
<td>CPU type</td>
<td>USTO Cluster</td>
</tr>
<tr>
<td>Emissions source</td>
<td>EMEP Inventory</td>
</tr>
<tr>
<td>Initial conditions</td>
<td>camx.v5.2.inst.5.2</td>
</tr>
<tr>
<td>Boundary conditions</td>
<td>camx.v5.2.BC</td>
</tr>
<tr>
<td>Meteorological data</td>
<td>Skiron Meteorological Model</td>
</tr>
</tbody>
</table>
CLIMATOLOGY OF THE EPISODE

The general meteorological conditions simulated (Fig. 2) were characterised by maximum surface air temperature (1200 UTC) ranging between 34 and 42°C over the Algerian Coast on the first day of the simulation, while the next days it varied between 34 and 40°C the following days over the same area. The temperature distribution over the western Mediterranean Basin (WMB) was associated with a weak Coast flow moving slowly eastwards, this situation induced weak cyclonic circulation over the western and central Algeria and an anticyclonic circulation over the Algerian troposphere over that region. Under this weak synoptic forcing, strong insolation may promote the development of mesoscale flows associated with the local topography (mountain and valley breezes), while the difference in temperature between the sea and the land enhances the development of sea-land breezes. However, the synoptic conditions are the main forcing associated with the long range transport of pollutants from Europe to North Africa. The temperature reaches 32-38°C over the Algerian coast at that time. Later in the day, the surface air temperature decreases also the Algeria coastal land begins to cool, while the air over the Mediterranean Sea is higher to generate an air flow between sea and land. After the sunrise on July 28th as well as the following day, a weak low pressure system exists over Algeria accompanied by a high pressure system over Tunisia and Libya moving slowly to the east with a depression over the Iberian Peninsula. The air temperature ranges between 38 and 42°C in the course of the day and during the night it ranges between 14 and 24°C. The synoptic situation over Algeria was coupled with the local airflow produced by the particular geography of the North Algeria during the period of the case study. The Algerian coastal plain serves to direct the air flow to and from the Mediterranean Sea. The nearby coastal hills of Algeria which contain the marine layer contribute in the trapping of pollutants like O$_3$ also this coastal mountains prevent this pollution layer from intruding too far inland. In addition, the local hills heat up in the daytime reaching an average of 34°C, giving rise to

![Fig. 2: Mean surface temperatures and mean wind velocity/direction over the Western Mediterranean Sea for 28-29 of July, 2013.](image)

![Fig. 3: Scatter plot of CAMx model vs observed Hourly Average Ground-level ozone for Languedoc-Roussillon, Pyrénées at 28th and 29th July, 2013.](image)
differences in surface air temperature near the earth and the higher layers, causes an inverse temperature layer.

The particular days were selected for the study, analysis, investigated of photochemical pollution formation and transport favoured by the synoptic meteorological conditions developed. These conditions correspond to a typical summertime period with intense insolation accompanied by a pressure synoptic system that favors high temperature field persistent over the region of interest, i.e. over North Algeria. This situation enhances the photochemical processes, which drive to a high concentration of ground-level O$_3$, therefore, affecting the air quality of the region. The meteorological patterns during the period 28-29 of July, 2013, fit a typical pattern for O$_3$ episodes.

Fig. 4: Hourly average O$_3$, NO and NO$_2$ concentrations at 1200 UTC, for 28-29 of July, 2013.

Fig. 5: Spatial distribution of O$_3$ tracer concentrations.
RESULTS AND DISCUSSION

a. Model validation: Fig. 3 presents typical levels of ozone as the smog process progresses at western North Africa. It presents ozone exactly at South of France: AIR Languedoc-Roussillon, Pyrénées measure Station situated at (latitude=43.6° longitude=3.88°). The predicted results from a CAMx simulation of the Pyrénées metropolitan area are compared with hourly monitoring data. A good concordance between CAMx model and measure station was noticed ($r^2=0.62427$, $r^2=0.51865$) respectively. A slight difference between the model results and observation data have been found due to the grid refinement.

b. Transport and transformation during the episode: The smog day begin as traffic and industrial builds to reach a maximum at around 0800 UTC, there is an attendant rapid increase in the concentration of NO occurs first, as these emitted from sources directly. The increase in NO$_2$ gaps by a short period because it is formed by atmospheric reactions. Shortly after sunrise and the photochemical reaction sequence, the NO concentration begins a rapid decrease and the oxidant predominantly ozone concentration increase at a similar rate. By 1000 UTC the photochemical process oscillate over the equilibria. Hourly average O$_3$, NO and NO$_2$ concentrations at 1200 UTC are shown in Fig. 4. There is the noticeable ozone in the air, increases until about 1100 to 1400 UTC (Fig. 5). At 1800 UTC the intensity of solar radiation has decreased to a low level and the photochemical process has dropped. Oxidant levels turn down rapidly as their production rates go to zero. By 0100 UTC (midnight) the concentration of oxides of nitrogen have again reached normal coastal levels (stagnant air conditions), and are ready to participate in more smog formation reactions the next day. 29th of July, ozone still is available from the reservoir layers (Costal hills) that it has not been depleted fully from the drainage flow, and the concentrations do not drop below 0.4 ppm during the night. While, the O$_3$ concentration at the Western North Africa more precisely at the Algerian Coast, is low compared to the South Europe area. At the 0800 UTC, the O$_3$ increases and reaches 0.6 ppm. This increase occurs with a weak wind speed. By 1000 UTC the wind speed at sea surface near the North Africa areas increase to attain 6 ms$^{-1}$. These two factors (rise of O$_3$ and wind field) create the transport of O$_3$ within the marine boundary layer in the reservoir layers above the sea. The O$_3$ reach its maximum of 0.85 ppm at 1200 UTC, at this time the situation is calm and stagnant. This timing the O$_3$ keeps increasing and when the maximum wind speed is attained the polluted air masses (O$_3$, NOx) are dispersed and transported to release a new photochemical production and accumulated above the sea. It reaches a maximum around 1400 UTC with a well-developed sea breeze at the Algerian Coast.

Fig. 6, displays the spatial distributions of the simulated tracer concentrations. CAMxTraceradvects the tracer too far southwest exactly to Gulf of Lyon and Northeast of Spain keeping a circular Gaussian plume distribution and reproduce the northwest to south diagonal orientation (Sea reservoir), afterward to North of Africa Exactly Algerian Coast. The CAMx dispersion models do a better job in reproducing the wind field distribution/direction.

Fig. 7 shows transect of O$_3$ concentrations, as it is shown in Fig. 1, from South Europe (SE: latitude=43.6° longitude=3.88°) to North Africa (NA: latitude=36.7° longitude=2.98°) at 1200 UTC of the day.

These charts show the continuity in transporting of studied species O$_3$, NOx for long distance. The most significant air pollution masses transported during this episode is O$_3$ with regards to the other species. Otherwise it can explain and quantified the air masses transported to the Algerian Coast.

CONCLUSION
The period studied (28-29 of July, 2013) was characterised
by a spell of calm and dry weather allowing pollutants to build up near Coastal line. The model results show prominent chemical transport from south Europe towards the western North Africa. The evolution of the concentrations of photochemical pollutants for a daily cycle in the lowest model layer, i.e. near the surface, over the Mediterranean Region show clear diurnal variations, varying from low concentrations at night and reaching maxima in the early afternoon over the entire modeled domain.

The long-range transport towards the Algerian Coast during this study were identified; from East Spain and South France. This transport of polluted air mass can be explained by the polluted air reaches the areas surrounding the Alps as well as the Western Coastal Spain (these region act as temporal reservoir), (1) part of these pollutants mainly $O_3$ and NOx could be present above the trade winds dominating these two regions (Azores high), (2) The pollutants ruminating in the lower layers could also travel by the marine boundary layer towards and along the Algerian Coast with the trade winds, i.e., the air flow occurs in the lowest layers, near the sea surface. This transport mechanism could be explained some high $O_3$ levels at the Algerian Coast background occurred in this period.

ACKNOWLEDGEMENTS

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REFERENCES


