MULTIPLE-LAYER AEROSOL STRUCTURES OBSERVED WITHIN THE BARCELONA AIR BASIN FROM REGULAR LIDAR MEASUREMENTS: MESOSCALE CIRCULATORY PATTERNS OF AIR POLLUTANTS IN TYPICAL SUMMERTIME SITUATIONS

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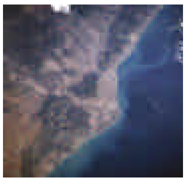
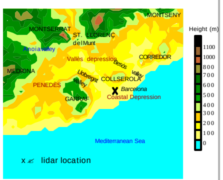
Introduction

Aerosols are emitted in the city together with other gaseous pollutants of interest in processes such as combustion of fossil fuels by cars, which is the main source of air pollution in Barcelona (Costa and Baldasano, 1996), or formed by gas-to-particle conversion in the atmosphere. Assuming that aerosols and other pollutants migrate together from the source (except for gravitational settling of coarse aerosols), the time evolution of the aerosol vertical profiles can be used to monitor the circulation of air pollutants within the region. Regular aerosol backscatter measurements using an elastic-backscatter lidar were performed since May 2000 for more than 2 years in Barcelona (Spain), a region with strong coastal and orographic influences. The vertical profiles retrieved in a regular schedule have confirmed the presence of multi-layered structures of aerosols above the mixing layer during numerous measurement days. Earlier evidence of this phenomena was found during an elastic-scanning lidar field campaign in 1992 (Soriano and Baldasano, 1998; Soriano et al., 2000). The analysis of the meteorological maps of the corresponding days show a common weak synoptic situation together with an intense solar heating which is typical in summertime around the region. These meteorological situations allow the development of mesoscale flows related to the daily heating and cooling cycle. Layers form when aerosols are injected from the mountains into the return flow that completes the sea-breeze circulatory cell. The regular monitoring of aerosols as tracers of wind motions together with numerical simulation results of the Barcelona atmosphere (Toll and Baldasano., 2000) explain the main circulatory patterns of air pollutants over the Barcelona Area in typical summertime situations which depend on daytime convective vertical mixing, sea-breeze circulations and mountain-induced winds.

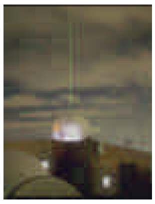
Description of the Barcelona Area

Barcelona is located on the shores of the Mediterranean Sea, on the northeastern corner of the Iberian Peninsula. Its location, together with the orography surrounding the region, contributes to the complexity of the dispersion of pollutants emitted in the region. The orography of the region is dominated by four main features arranged parallel to the coastline: (1) the coastal plain, which comprises an 8-km strip of land between the sea and the first mountain range and which includes most of the cities in the greater urban area of Barcelona; (2) the coastal mountain range with altitudes between 250 and 512 m; (3) the pre-coastal depression (Vallès depression), situated between the coastal mountain range; and (4) the pre-coastal mountain range, with maximum altitudes of about 1500 m. There are two main river valleys in the area: Llobregat and Besòs. These rivers frame the city and their respective valleys play an important role in the establishment of air-flow patterns.





The Barcelona UPC lidar

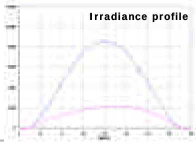


The UPC lidar system combines 2+1 elastic/Raman channels plus a scanning feature into a single portable 3-D-*scanning Raman lidar* (SRL) instrument. The aerosol elastic-backscatter lidar system of the UPC Barcelona is based on a Nd:YAG laser emitting at 1064 nm and 532 nm.

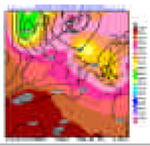
Regular measurements are performed on Monday at 14:00 LST (local solar time) +/-1 hour and at sunset -2h/+3h and on Thursday at sunset -2h/+3h

Meteorological settling and typical summertime scenarios

The Iberian Mediterranean coast presents differentiated meteorological features from the central and northern regions of Europe and from the Atlantic Iberian regions, derived from its location with respect to the surrounding meteorological synoptic systems, the complex orography of the region and a high degree of insolation and scarce rainfall. The meteorology and the origin of the air masses arriving at the Iberian Peninsula are highly influenced by the Azores high pressure system that is located over the Atlantic Ocean and that intensifies during the warm season. From spring to autumn, barometic swamps or anticyclonic situations with weak pressure gradients occur all over the region. Under this low pressure horizontal gradient scenarios, sea breeze and montain induced winds predominate in such a way that pollutants are re-circulated and polluted atmospheric layers are developed at several heights.



Irradiance profile

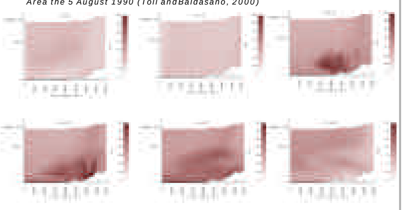


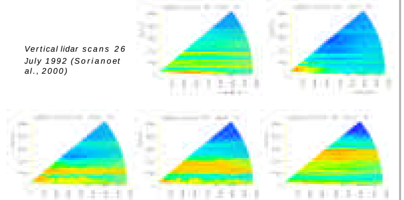
Barometric swamp

Previous research

Soriano et al. (1998, 2000) studied the circulatory patterns of air pollutants in the area of Barcelona with both lidar data and numerical simulation. Vertical lidar scans were performed under a weak synoptic situation on the period 26-28 July 1992 and revealed a multilayer arrangement of pollutants over Barcelona. Toll and Baldasano (2000) chose the 5 August 1990 with similar synoptic conditions to model photochemical air pollution in the Barcelona area. In fact, the highest levels of pollutants in the region are usually reached in summertime under weak pressure gradient conditions. The simulation results, from both meteorological and photochemical dispersion modules, were compared with measurements from surface stations, and proved to be fairly similar. The results show upper air layers of O_3 caused by the reinforcement of the sea breeze in the coastal range (upslope winds) that injects ground air masses towards upper layers of the PBL. No measurement data were available to evaluate the model in the upper air layers. Millán et al. (1997) have also reported the presence of upper air polluted masses in eastern Spain.

Photochemical dispersion simulation of the Barcelona Area the 5 August 1990 (Toll and Baldasano, 2000)



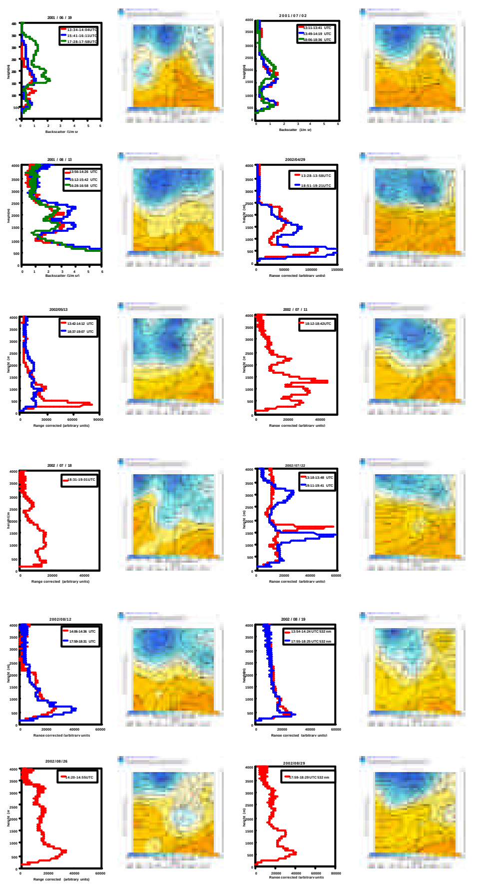


Vertical lidar scans 26 July 1992 (Soriano et al., 2000)

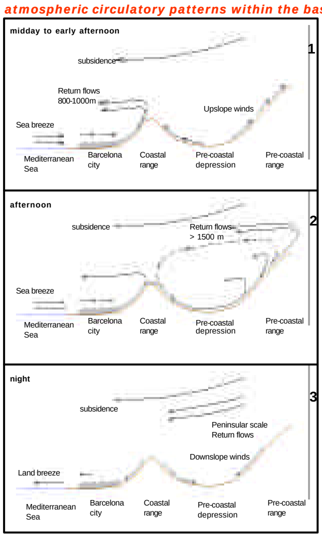
Lidar regular measurements

Since May 2000 the Barcelona lidar station has observed numerous aerosol vertical profiles presenting a multi-layered arrangement of aerosols. The meteorological situation around Barcelona was typical of summertime for the region with a weak synoptic situation above the Iberian Peninsula. The figures on the right show lidar backscatter and range corrected vertical profiles (averaged over 30 minutes) presenting vertical distributions of aerosols over the ML in layers of different height and thickness. Many aerosols are emitted into the atmosphere during the morning. As solar radiation increases, turbulence intensity increases and a ML forms. The ML over land during this time of the year in the Barcelona region grows to a maximum height of 800-1000m at about 13:00 LST (11:00 UTC) (Soriano et al, 2001). The height of the aerosol layers vary from 1000 to 4000m and the thickness range typically from 100m to 1000m.

The weak synoptic situation (weak pressure gradient) together with intense solar heating allows the development of mesoscale flows related to the daily heating and cooling cycle. Layers form when aerosols are injected into the return flow that completes the sea-breeze circulatory cell. As the day progresses and the breeze penetrates further inland, the circulatory cell associated with it grows, and its associated return flow occurs at higher altitudes. Orographic injections of aerosols from the surrounding mountains are added to this return flow.



Schematics of the mechanisms determined as important in the development of atmospheric circulatory patterns within the basin for a typical summertime situation



Information from the lidar and the model simulations are used to explain the circulatory patterns of air pollutants in the Barcelona Air Basin. The first mechanism is for the typical midday to early afternoon situation (1), characterized by sea-breeze inland flows, upslope winds in the mountain ranges, and up-valley winds in the river valleys. Return flows from the sea-breeze circulatory cell and from the orographic injection of the mountains of the coastal range take place between 800-1000 m, dependent on the depth of development of the circulation cell. The high altitude situation is dominated by a general subsidence caused by the high-pressure area located above the region at the synoptic scale.

The mid-afternoon situation (2) also shows a general inflow circulation typical of the daytime period. However by this time, the sea breeze has penetrated over the coastal mountains and its associated front has reached the pre-coastal mountain range. A circulatory cell between the two mountain ranges appears. In addition, return flows produced by orographic injections of this second higher mountain range are situated at higher altitudes, above 1500 m. Subsidence persists aloft.

The final situation (3) corresponds to the nighttime regime, i.e., the sea breeze has reversed and a general offshore flow is now present. This offshore flow is characterized by the combined effects of land breeze, drainage valley winds, and downslope winds in the mountains. Subsidence persists on the synoptic scale, and effects from peninsular-scale phenomena are now more evident. As a consequence of the Iberian thermal low centered on the peninsula at this time of the year, pollutants from its centre rise up and then diverge toward the coast during nighttime. This return flow takes place at even higher altitudes (2000- 4000 m) and explains elevated aerosol layers imaged by the lidar during the night and early morning scans the during a typical summer day during midday, afternoon and night periods.

Concluding remarks and future work

Mesoscale circulatory patterns are mainly determined by the orography of the region. The lidar profiles from a large measurement period (may 2000 – december 2002) in the frame of EARLINET have shown a multilayer arrangement of aerosols over the Barcelona region during typical summertime situations in the absence of large scale forcing. This was previously observed in other works by lidar techniques and numerical approach (Toll and Baldasano, 2000; Soriano et al 2000). The combination of lidar data with meteorological mesoscale models provides an explanation of the circulatory patterns of pollutants within the Barcelona air basin and demonstrates its suitability to study atmospheric circulations and boundary layer structure at a regional to local scale.

Future measurements will be performed with the recently upgraded UPC lidar system, integrating a Raman channel and scanning capabilities, in order to quantitatively retrieve optical properties of the aerosol layers and deepen in the comprehension of the transport patterns of pollutants within the region.

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