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Study of the land-sea interface in the Barcelona Area with lidar data and meteorological models

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Abstract

This contribution analyzes the circulatory patterns of air pollutants in Barcelona (Catalonia, Spain), an area with strong coastal and orographic influence, during a typical summer-time situation. Special emphasis is put on the development of the sea-breeze circulation and the penetration of its front in the terrain. The analysis was carried out using data from an elastic-backscatter lidar and results from the application of a mesoscale meteorological model. Vertical scans from the lidar revealed a multilayer arrangement of the aerosols above the city, which is related to the sea-breeze circulations and the mountain and valley winds that originate in the region. The formation of a thermal internal boundary layer above the city, as cold and stable air from the sea flows over the heated surface, was also captured with the lidar. The non-hydrostatic meteorological model MEMO was applied to the Barcelona Area. A dispersion simulation, using CO as a tracer, was also carried out, whose aim is the identification of the atmospheric circulatory patterns in the region. Results from the model helped to understand the information acquired with the lidar to make a full description of the circulatory patterns of air pollutants in the Barcelona air basin.

1 Introduction

Being located near the Mediterranean coast, the city of Barcelona and its area of influence provide a privileged scenario for the study of the land-sea-air interactions. Regions with complex orography and a strong coastal influence develop a very wide range of meteorological phenomenology that makes this kind of domains very attractive to the study. The main processes going on coastal environments are daytime convective vertical mixing, sea-breeze

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circulations, and circulations produced by mountain and river valley thermal and mechanical effects [1], [2], [3].

These mesoscale phenomena develop better when the synoptic conditions prevailing at large scale is weak. When the mesoscale conditions prevail, circulatory patterns will be mainly determined by the characteristics of the terrain in the area. A region's unique orography often requires the development of unique air-quality schemes at a regional scale [4]. That is evidenced in the frequent fact that air-quality remediation schemes developed for one region often prove useless when applied to other areas.

The mesoscale circulatory patterns of air pollutants in the region of Barcelona were described in a study that combined experimental measurements with numerical simulations from meteorological and dispersion models [5]. The application of these two approximations proved very useful for this kind of study, since they compliment each other. Measurements consist mainly of elastic-backscatter lidar data. The lidar data were acquired in July 1992 during a collaborative campaign carried out between Los Alamos National Laboratory (LANL), Los Alamos, NM (USA), and the Technical University of Catalonia (UPC), Barcelona (Spain). The lidar provided information about the distribution of aerosols and the prevailing winds.

In this contribution, we will focus in the dispersion study rather than in the meteorological component of the simulation with the mesoscale model, and we will put the stress on the development of the sea-breeze circulation and the penetration of its associated front in the terrain. The role that mountains in the area have in the establishment of the circulatory patterns will also be studied.

2 Lidar observation of the mesoscale circulations

Vertical scans of range-corrected elastic-backscatter from the lidar can map the distribution of aerosols within the atmosphere, and can be used to infer the patterns of air pollutant circulation in the monitored region. This capability follows from the fact that aerosols trace flow and mass motions within the atmosphere, and have been used in the description of the circulatory patterns of air pollutants in Barcelona mentioned above. Figure 1 shows the evolution of the Mixing Layer (ML) as captured by the lidar, as a function of range from the lidar (x-axis) and m.s.l. altitude (y-axis). Light colors indicate high content of aerosols, whereas dark colors indicate low presence of aerosols. As we move away from the lidar we are approaching the sea, which is at about 6 km from the lidar's position.

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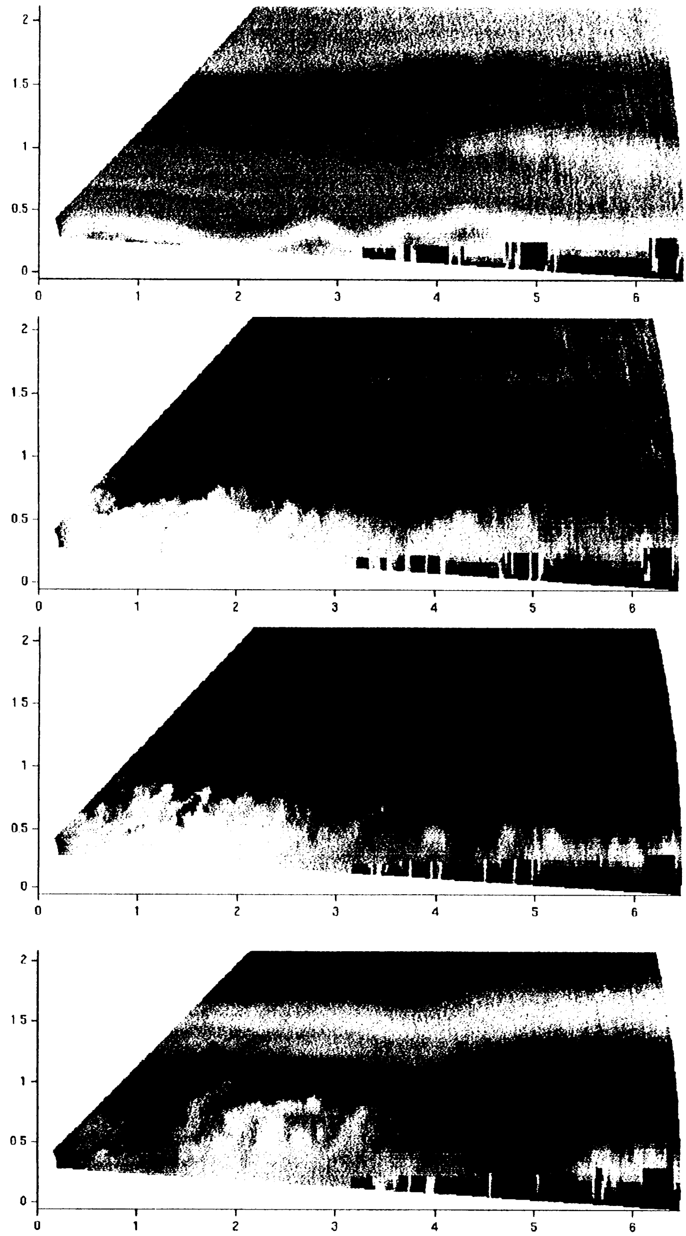

Figure 1: Lidar vertical scans of elastic backscatter acquired in Barcelona, on July 28, 1992, at (from top to bottom) 5:21, 11:36, 13:35 and 14:34 LST. (Y-axis is altitude and X-axis is range from lidar, both in km. Light/dark colors indicate high/low content of aerosols).

The scans show the structure of the first 2.5-km of the atmosphere in Barcelona. Scan at the early morning shows a shallow Nocturnal Boundary Layer (NBL) of about 300-400 m. During nighttime we talk of NBL rather than ML because mixing is reduced. Offshore flow (moving away from the lidar position) is evident in this layer, and produce waves in the frontier between clean and dirty air. Daytime scans show a development of the ML, evident in the lidar scans as a highly convoluted layer with origin in the surface, where aerosols (and pollutants) are emitted. The maximum depth of the ML is observed at about 13 LST. Under conditions of light onshore winds and strong insolation, the ML becomes a Thermal Internal Boundary Layer (TIBL) in coastal zones ([6], [7]), which shows a continuos rise from its over water depth to a continental depth. This rise of the TIBL is clear in the scan acquired in Barcelona at 13:35, where we can see that it has an altitude of 400 m at 6 km from the lidar position (next to coast-line), and rises up to 800 m inland. Finally, the scan at 14:34 shows an elevated layer of aerosols at about 1.5 km of altitude. Those aerosols are positioned aloft by the return flow of the sea-breeze circulatory cell and the injection produced by the Coastal Mountains, the mountain range limiting Barcelona city in its interior side and where the lidar was installed during the campaign. Convection is still evident on the ML, and we can also identify some Kelvin-Helmholtz billows. These kind of circulatory cells are formed as air masses with different density (sea-air and terrain-heated air) find each other.

3 Dispersion Simulation

A dispersion simulation has been carried out with the mesoscale model MEMO [8]. The simulation was performed CO, a very low-reactive pollutant, to be used a tracer of the atmospheric movements. The simulation domain is a region of 80x80 km^2 centered in the city of Barcelona, with a cell resolution of 2x2 km^2. The CO inventory for Barcelona was extracted from the emission inventory for year 1990 [9]. Results from that inventory were that 90% of the total emissions of CO in the region are from traffic.

The simulation day chosen was 28 July 1992. The weak synoptic situation for that day allowed the development of the mesoscale phenomena that takes place in the region. The evaluation of the meteorological model with data from surface station and remotely measured winds with elastic lidar was shown in [5]. We will show here the results of the dispersion simulation. Figure 2 shows the horizontal fields (at 10 m above the surface) of CO calculated by the model for 6 LST and 18 LST. Two different scales have been used, as the increase of the ML during daytime provokes a dilution of

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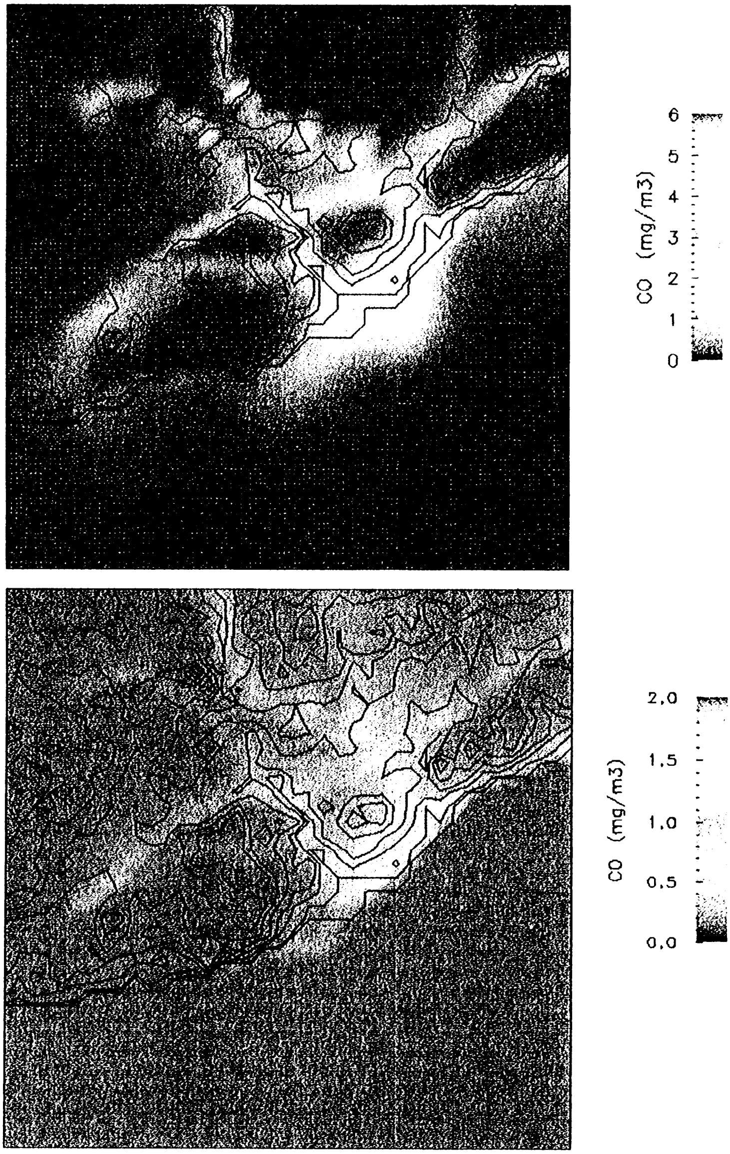

Figure 2: Horizontal cross-sections of the CO concentration (in mg/m^3) at 7 LST (top) and 18 LST (bottom) on July 28.

the emissions in the afternoon. The CO distribution reveals the main aerosols sources in the region (Barcelona City and main roads). At 7 LST the offshore flow produce a migration of the CO emitted in the land towards the sea. The situation reverses as sea breeze starts to blow, and provokes a penetration of the pollutants inland. We can see this penetration in the plot for 18 LST in the afternoon. The rise of the ML decreases surface concentration levels of CO (and pollutants in general), compensating higher emissions at that time of the day.

The vertical cross-section of CO concentration at 11 LST is shown in figure 3. We can identify the TIBL that is formed above the land. It is shallow above the sea and next to the coastline (right side of the plot) and gets deeper as we move inland (depths of about 600 m at that time of the day). The plot is in agreement with the aerosol distribution captured by the lidar and represented in the form of vertical scans.

Figure 3: Vertical cross-sections of the CO concentration (mg/m^3) simulated by the model at 11 LST, on July 28, 1992. Altitude is in meters.

Cross-sections of CO concentration for next times (not included here) show the development of the ML (to a maximum depth of about 900 m) and some transportation of CO to high altitudes, specially the injection produced by the mountain ranges that we had identified in the lidar scans. However, this injection is reproduced later in the afternoon by the model, and only in the Pre-Coastal Mountain range.

4 Evaluation of the dispersion simulation

The evaluation of the dispersion simulation has been carried out by comparison with data from surface stations in the domain. Results of this comparison are shown in figure 4.

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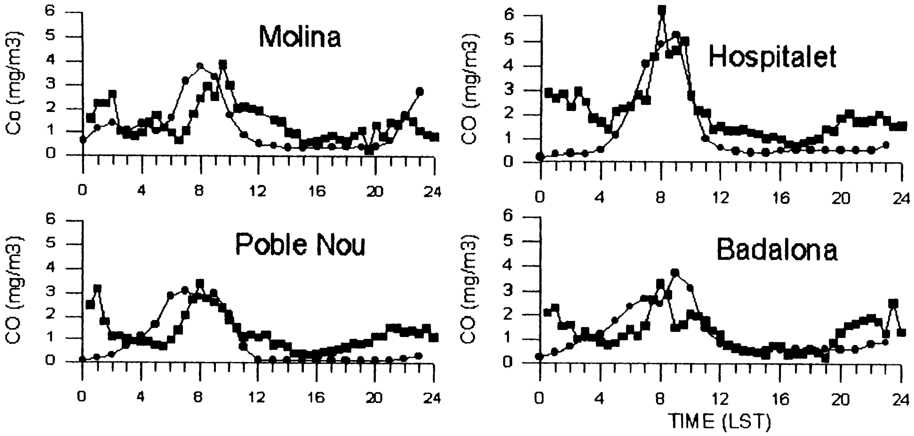

Figure 4: Comparison of the concentration of CO (in mg/m^3) simulated by the model (circles) with measurements from surface stations (squares) for July 28, 1992.

As we can see, the agreement between measured and simulated data is quite good. The model was able to simulate very well, both in time and magnitude, the position of the maximum of the CO concentration. This maximum takes place between 8 and 10 LST, when higher emissions (rush hour time) coincide with a still shallow ML, since solar radiation is still weak at this time of the day. Even the higher pick registered at the station of Hospitalet was reproduced by the model.

5 Conclusions

We have studied the penetration of the sea breeze front in the region of Barcelona. Lidar scans have captured the development of a TIBL (Thermal Internal Boundary layer) above the terrain as cold and stable air from the sea flows over the terrain. A dispersion simulation has been carried out for the region, using CO as a tracer of the atmospheric movements. Results have shown how the dispersion of pollutants is highly determined by the daily cycle of the sea breeze circulation and the mesoscale circulations originated by the complex surrounding orography in the region. Evaluation with surface stations has given excellent results, and the model has reproduced the formation of the TIBL.

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