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SEASONAL VARIATION OF THE ATMOSPHERIC CIRCULATORY PATTERNS IN THE BARCELONA AREA: NUMERICAL SIMULATION OF TYPICAL WINTERTIME AND SUMMERTIME SITUATIONS

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1. INTRODUCTION

This contribution analyzes the circulatory patterns of air pollutants in Barcelona (Spain), an area with strong coastal and orographic influence, during two typical summertime and wintertime situations from the meteorological point of view.

Summertime and wintertime modeling scenarios were extracted from the study of series of synoptic maps for the region. Since the intention was to simulate the mesoscale flows in the area, the synoptic situation in both cases was chosen to be weak, so that no important large-scale forcings were introduced. The lack of large-scale forcings allowed the development of mesoscale circulations. Climatological studies include both situations as typical meteorological situations for the region (Atles Climàtic de Catalunya, 1996).

The simulations were performed with the latest version of the non-hydrostatic meteorological model, MEMO (Moussiopoulos, 1994)

2. THE STUDY REGION

Barcelona is located on the northeastern corner of the Iberian Peninsula by the Mediterranean Sea, and presents an opportunity to study the air-water-land interface. Barcelona's location, together with the orography surrounding the region, contributes to the complexity of the dispersion of pollutants emitted in the region.

The region that should be taken into consideration to analyze the circulatory patterns of air pollutants in the Barcelona area covers an extension of 80x80 km^2 around Barcelona City (Fig. 1). Although the city by itself covers a much reduced area, the domain chosen was larger because earlier studies (Baldasano *et al*., 1994) in the Barcelona area indicated that that area contains most of the orographic features which cause the winds seen in the area.

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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 mountain range, and includes Barcelona and other 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, which is situated between the coastal mountain range and (4) the pre-coastal mountain range, which is the last dominant orographic feature and is defined by maximum altitudes of ~1,500 m). Finally, we note that there are two main river valleys in the area: the Llobregat and Besòs. These rivers frame the city and play an important role in the establishment of the airflows, mainly due to the canalization effects they introduce.

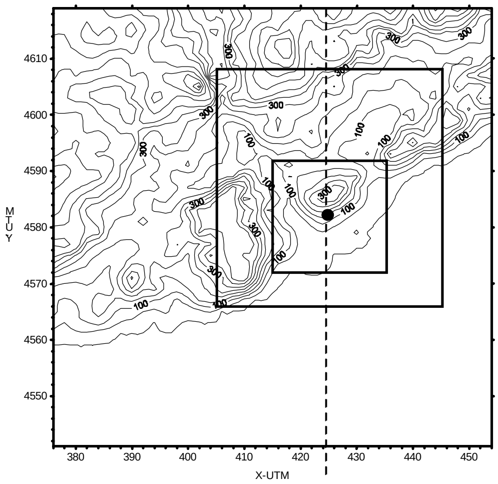

Fig.1. The Barcelona Geographical Area and the domains used for the simulations (inner domains were only used for the summertime simulation)

3. SUMMERTIME SITUATION

In July 1992, the UPC and LANL carried out the Barcelona Air Quality Initiative (BAQI) campaign. The atmosphere above Barcelona City was continuously monitored with an elastic-backscatter lidar device developed at LANL. The synoptic situation during the

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1992 campaign, and specifically for the 28 July 1992, the day chosen for simulation, can be described as weak (as can be seen in Fig. 2). High pressures dominate over the Atlantic and most of continental Europe. A low-pressure center is located to the Northwest of Ireland. The baric gradient above the Iberian Peninsula is very weak and a thermal low (due to the intensive heating of the terrain) is starting to develop over the Peninsula. Under such situation, mesoscale phenomena will develop and will play an important role in the dispersion of pollutants emitted in the region.

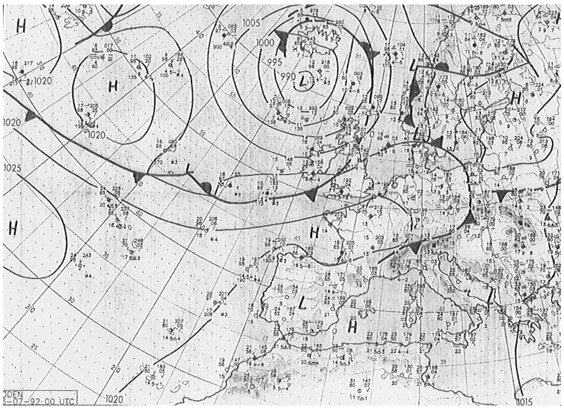

Fig.2. Surface synoptic situation at 0 GMT (Greenwich Meridian Time) on July 26, 1992.

The simulation began at 21LST (Local Standard Time, GMT+2 in summertime) the preceding day and ran for 27 hours. Radiosonde data acquired in Barcelona at 6 LST provided the initialization, or the initial state, for the MEMO, and was completed with information from launchings at Zaragoza and Palma de Mallorca at 0 GMT and 12 GMT, which were used as boundary conditions at middle times of the simulation. Sea temperature was fixed at 24°C.

For this occasion one the goals of the study was to evaluate the wind fields simulated with elastic-backscatter remotely measured winds (Soriano, 1997). That is the reason why we decided to run the simulation with nested grids in order to obtain a high density wind field in the inner domain and be able to evaluate as many model cells as possible with the lidar winds. The three domains used for the simulations were: (1) a coarse grid domain covering an area of 80x80 km^2 with a grid resolution of 2x2 km^2 (2). a medium grid covering a region of 40x40 km^2 with a 1x1 km^2 cell, and (3) a fine grid, which covers 20x20 km^2 with cell sizes of 0.5x0.5 km^2 in the lidar monitored area

The study of the MEMO two-dimensional wind fields demonstrates the model's ability to simulate the on-shore and off-shore cycles, typical of the sea-breeze circulation within the greater Barcelona air basin. Fig. 3 shows wind fields calculated by the model for the coarser grid at 16 LST. The plot shows the typical wind flow for an afternoon situation. These flows are characterized by on-shore winds from sea to land produced by the sea breeze, up-slope winds in the mountains, and up-valley winds. The important solar radiation during this time of the year provokes a heating of the terrain causing winds of up to 7-8 m/s, and the orientation of the mountain ranges parallel to the coastline causes upslope winds in the same direction as the sea breeze flow. For these reasons, the sea-breeze front is not evident in the two-dimensional wind field plots. However, we can see that winds a few kilometers inland are stronger than the coastal winds, implying that the effects of the mountain winds are coupled to the inshore winds generated near the coast.

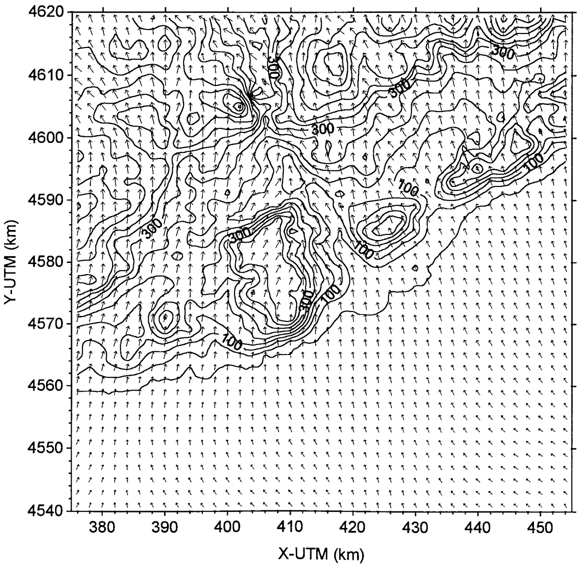

Fig.3. Wind field simulated at 16 LST on July 28, 1992 for the coarse grid.

A vertical N-S cross-section of the winds (*u-v* components) simulated at 16 LST on the coarser grid is shown in Fig. 4.(the position of the cut is in Fig. 1) The plot shows a well developed sea-breeze that has penetrated until the Pre-coastal Mountains. The vertical extension of the circulatory breeze is of the order of1km.

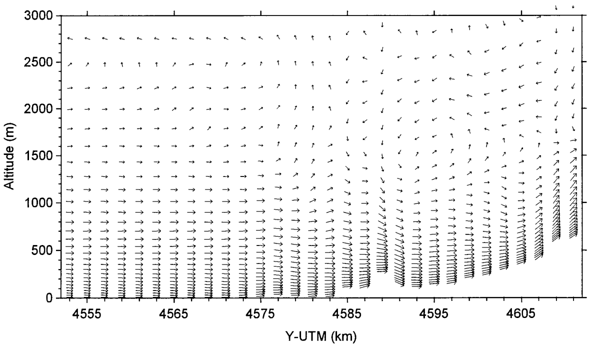

Fig.4. Vertical cross-section (N-S) at 16 LST on July 28, 1992 for the coarse simulation domain.

The evaluation of the model has been performed by comparison with measurements from surface stations. Comparison with two of the stations is show in Fig. 5. The graphs show good agreement between the simulated winds and the measured winds. The model accurately predicted the diurnal cycle, and the timing of the transition from the nighttime to the daytime situation. Also, the graphs do not show that the nested grids produce an important improvement in the simulated winds. This would imply that the resolution of the orography for the coarser grid is adequate to originate the main circulatory patterns in the area.

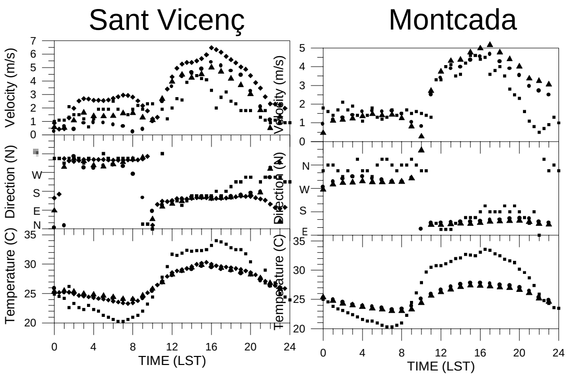

Fig.5. Evaluation of the simulated (● coarse, ▲ medium and ◆ fine grids) winds and temperature with surface station data (■)on July 28, 1992.

We have been able to extend the evaluation of the model performance to high altitudes by comparing the winds calculated by the finer grid with the winds remotely measured by the lidar. The importance of this comparison is that lidar-measured winds are free of the surface-related local features that measurements from surface stations may include (Soriano *et al*, 1997). Fig. 6 shows a comparison between simulated and lidar winds measured at 12:30 LST. Since winds from the lidar are obtained along the line of view of the laser beam, winds have been represented as a function of 'range from the lidar' in the x-axis and 'msl-altitude' in the y-axis. The simulated winds included correspond to the cells the laser beam crosses during its travel from the lidar.

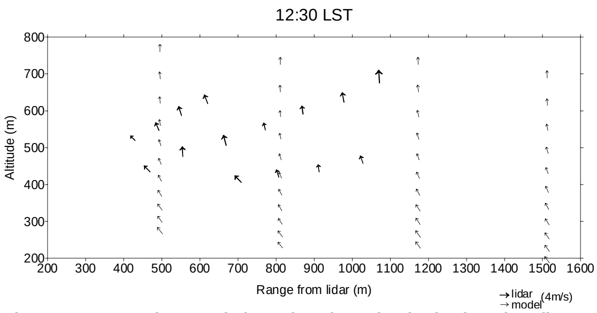

Fig.6. Comparison of the simulated winds for the fine grid and lidar measured winds at 12:30 LST on July 28, 1992.

The model shows a sea-breeze circulation from the SE, which is developed from the lower portion of the atmosphere. Differences between lidar and model winds are of the order of 0.5 m/s in velocity and as few as 5° in direction.

3. WINTERTIME SITUATION

The day chosen for the analysis of a typical wintertime situation in the region of Barcelona was the 21tst of January of 1993. The synoptic surface chart for that day is included in Fig. 7.

An anticyclone is centered over the Iberian Peninsula extending into France where a secondary high can be observed. Northern Europe is affected by the passage of a front, which causes a well-defined eastward circulation. It could be described as a northern anticyclone advection situation over the study area.

Radiosondes from Palma de Mallorca were used for initialization. Sea temperature was fixed at 12°C (note the difference with respect to the sea temperature used for the summertime simulation).

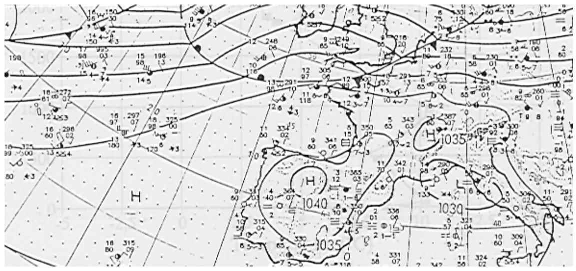

Fig.7. Surface synoptic situation at 0 GMT on December 21, 1993.

The simulation of the winter episode was carried out over the 80x80 km^2 (2X2km^2) domain. Fig. 8 shows wind fields calculated by the model at 16 LST (GMT+1 in wintertime). The plot shows a general inflow situation typical of the daytime situation.

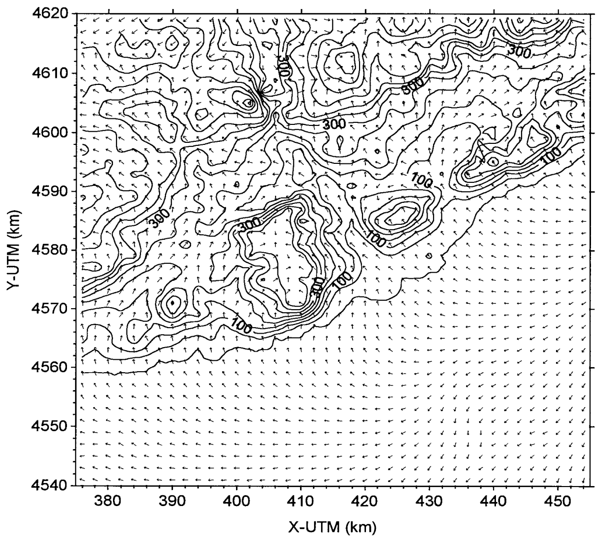

Fig. 8. Wind field simulated at 16 LST on December 21, 1993.

However, winds are now much weaker than they were for the summertime situation (in this case the maximum speed at this time of the day is only 3 m/s). The correspondent vertical cross-section at 16 LST

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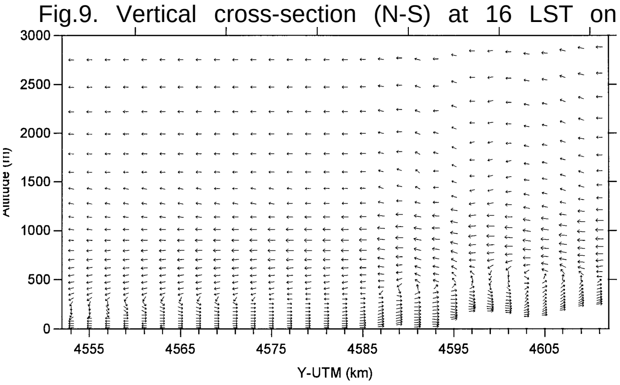
(Fig. 9) also shows a sea-breeze depth of only a few hundreds meters and of weaker intensity.

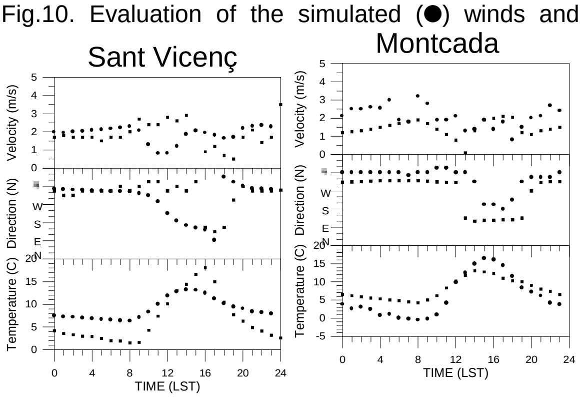
Fig.9. Vertical cross-section (N-S) at 16 LST on



December 21, 1993.

In fact, if we make the evaluation with the same stations that we used in the summer episode (Fig. 10) we can see how the time span of the sea-breeze flow during this time of the year is of only of a few hours.

Fig.10. Evaluation of the simulated (●) winds and



temperature with surface stations data (■) on December 20, 1993.

We can see how the sea-breeze at this time did not penetrate inland all over the study domain as it happened in the summertime simulation. We can still see upslope winds on the NW slopes of the Pre-coastal Mountains while in the summer simulation these had been cancelled by the inland flow of the breeze. So, while the shift in the flow which marks the start of the sea-breeze penetration takes place at around 9-10 LST in summertime, and spans for all the afternoon and early evening, in wintertime the shift to the daytime regime takes place around noon and last only for a few 4 hours. The river valleys play an important role in the canalization of the flows in the region. Upvalley winds are evident in both simulations, and its correspondent drainage flows during nighttime where reproduced by the model (not shown).

Finally, in both cases, summer and winter situations, the comparison between the simulated and the measured temperatures show that the change this parameter experiences along the day is softer in the modeled results. This can be explained if we take into account that results from the model have been calculated on the first layer of the simulation domain, which is situated 10 m above the surface. The surface stations acquired temperature measurements at 3 m above the terrain. This explains its higher variability along the daily cycle.

4. CONCLUSIONS

Typical summertime and wintertime situations have been modeled with the mesoscale model MEMO. In both cases the model has been able to reproduce the typical mesoscale circulations that develop in the Barcelona area due to its coastal location (sea-breeze) and its complex surrounding orography (slope and valley winds).

Results have shown that the main differences between the mesoscale circulations developed in summertime and wintertime are found in the intensity and duration of the sea-breeze inland flow during the afternoon. The stronger temperature gradient between sea and land during summertime provoke a very intense onshore flow that starts early in the afternoon and spans for 8 hours or more. On the contrary, during wintertime, wind speeds are much more uniform along the day and sea breeze blows later in the afternoon and only for a few hours (3 to 4 hours). Coupling between sea-breeze and mountain winds is evident in the summertime situation, while it is almost not present in winter. Drainage from the river valleys is reproduced in the two cases and, together with the land breeze typical of the nocturnal period, transports air pollutants that are produced over the terrain towards the sea were they are incorporated to large scale circulations.

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