OBSERVATIONS OF COMPLEX TERRAIN FLOWS USING AN ACOUSTIC SOUNDER

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Abstract

To develop and test better models of transport and diffusion of pollutants in complex terrain areas, a variety of programmes and field experiments have been carried out. As part of this programme, in this study we examine with a Doppler Sodar (FAS 64) several echo and wind pattern characteristics associated with different meteorological phenomena, which are related to the complexity of the terrain. To test the validity of different flow fields connected with Sodar patterns, such as slope drainage winds, cool-air accumulation in low-lying regions, channelling flows created by terrain constrictions (Venturi effects) and sea breeze flows, numerical simulation with the MM5 model was performed. The results show relatively good agreement between thermal structures and wind field given by the Doppler Sodar and numerical models.

Keywords : Complex terrain, Sodar, Mesoscale models, Wind fields.

1. Introduction

Several experimental campaigns and different studies have been done to analyse orographic flows, and to establish their basic dynamics, which are necessary to improve models of transport and diffusion of pollutants (Neff and King, 1987; Holden et al., 2000).

In terms of air quality planning, it is important for local authorities to have some idea about the governing flow field and the thermic inversion conditions at very complex areas located not far from big cities surrounded by industrial areas. This is the case of Barcelona and an orographic complex area named "La Plana de Vic", usually referred to as "La Plana", located in the Northeast sector of Barcelona's area. The complexity of this area, almost completely surrounded by mountains as it has only two narrow channels to connect it with neighbouring areas, develops flow patterns difficult to explain. In this paper, we focus our attention on the study of flow fields which connect both areas; that is, fluxes originating on the coast which flow into "La Plana", as the sea breeze, and air fluxes originated in "La Plana" which flow outwards as (channelling flows). Both fluxes possess very different physical and chemical characteristics, so their study is of great interest. Special attention is dedicated to drainage flows generation and the accumulation of cold air inside "La Plana", which afterwards will cause channelling flows, with the consequent exchange of air masses. With the goal of obtaining more information than the data generated by the Doppler Sodar and the network of ground stations, several numerical simulations of the different flow fields mentioned above have been made. Its help may bring additional information and contribute efficiently to the study of the mentioned air flows.

2. The experiment

2.1. Area description

The studied area called "La Plana", (see figure 1), is a large basin (a plain surrounded by mountains which are very often higher than 1000 m above sea level), whith height between 450 m and 600 m.

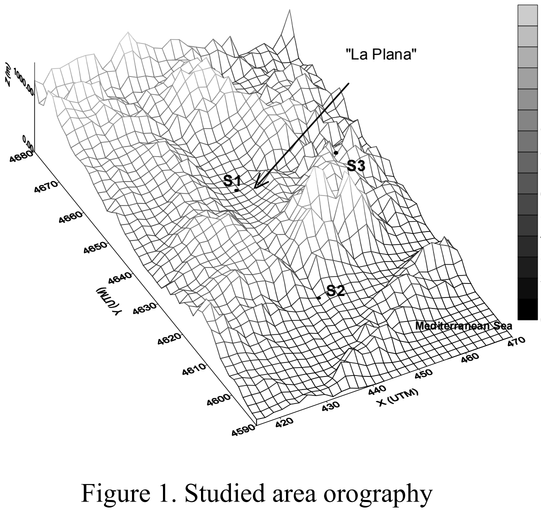

Figure 1. Studied area orography

This zone can be considered almost isolated (there are only two exits) referring to macroscale atmospheric circulation. In the south, the "Congost" exit, S_2 is located between the Tagamanent and Berti Mountains; and in the east, the Ter exit, S_3 is called "Les Guilleries", however is almost closed due to terrain constrictions.

This complex orography results in a particular thermic and dynamic regime in the area studied, as will be widely commented in point 3. In this section, we only highlight two phenomena, which have a climatic value due to their frequency.

The first one is the stagnation taking place at night, usually in anticyclonic situations; then the wind regime is calm (an average of 77% of the data analysed). The height of this stagnation is roughly 100 metres, causing stagnant cold air masses, and the formation of strong thermic inversions and fog; so the number of days with fog can reach 80 by year.

The second phenomenon is the occurrence of sea breezes, which starts in spring and ends in autumn. Thus, the area has pollution problems caused, on one hand, by the weak dispersive capacity of its air, and on the other hand, by the arrival of pollutants from industrial coastal areas when the wind regime is dominated by the sea breeze.

2.2. Experimental set-up

The Doppler Sodar used is a SCINTEC FAS64 Sodar (phased array) that was deployed initially in the Manlleu area, S_1, located in the lowest part of "La Plana". The Sodar worked almost continuously from April 2000 to September 2001. Afterwards, during February 2002, it was installed at the exit of the "Congost", S_2, to study channelling flows.

The Sodar works in a cyclical form. Each cycle is defined by different pulse sequences, which are sent up to 9 beam directions, which correspond to Vertical/East/North/West/South directions (29º) and the mirrored direction (-22º). Each pulse sequence, in total 10 (in our configuration) consists of up to 10 pulses (9 in our configuration). Pulses always alternate between the main direction and the mirrored one.

In addition, data from a network of meteorological ground stations are used in this study.

2.3. Mesoscale model

The mesoscale model used in this study is the MM5, (Grell et al. 1994). Four domains two ways nested are defined using the following resolution: 27, 9, 3 and 1 km. The dimensions of each domain are: 31x31 for the two outer domains, and 37x43 and 37x61 grid points for the two inner domains, respectively. The smallest domain covers an area from 41.6 to 42.1 N and 2.1 to 2.5 E in order to simulate the sea breeze entrance. The initial and boundary conditions are updated every six hours with information obtained from the ECMWF model with a 0.5ºx0.5º resolution. For the two inner domains, we use a topography and land-use data base with 30" resolution. For the two outer domains the horizontal resolution is 1'. High vertical resolution is prescribed in the ABL, 14 levels, with higher resolution on the low levels.

3. Main wind circulations

In this section, we will consider main wind circulations observed in this area: sea breeze, drainage and channelling winds.

3.1. Sea breeze

One of most frequently measured and observed phenomena is the sea breeze, which comes into "La Plana" from its southern entrance, "el Congost". It takes place from spring to autumn with a changeable duration: between 9 and 4 hours. Its maximum speed is between 10 and 5 ms^{-1} at 150 m high from the measured place. In the cases studied, we don't observe its return because it is located above the vertical range of Sodar (500-600 m). Visualization of the echo return shows the arrival of the sea breeze as a small cold front reflected as a narrow line of strong return. According to Neff (1986), this return is caused by the change between the relatively cold and stable air from the sea and the warm and unstable air above the surface.

The sea breeze is very important because it is the main cause of pollutants advection in "La Plana", especially ozone and its precursors. Soler et al., (2001) show that ozone concentration in the area double with the arrival of the sea breeze. With any other wind regime, measured ozone concentration in "La Plana" is lower.

In figure 2, one can observe the time height cross section of the S-N (v) wind component, measured by the Sodar installed in "La Plana", (S_1 in figure 1), corresponding to a typical day of sea breeze. It can be observed that it starts approximately at 13 UTC and develops during 9 hours aprox. Its height is above the vertical range of Sodar, with a maximum of $6ms^{-1}$.

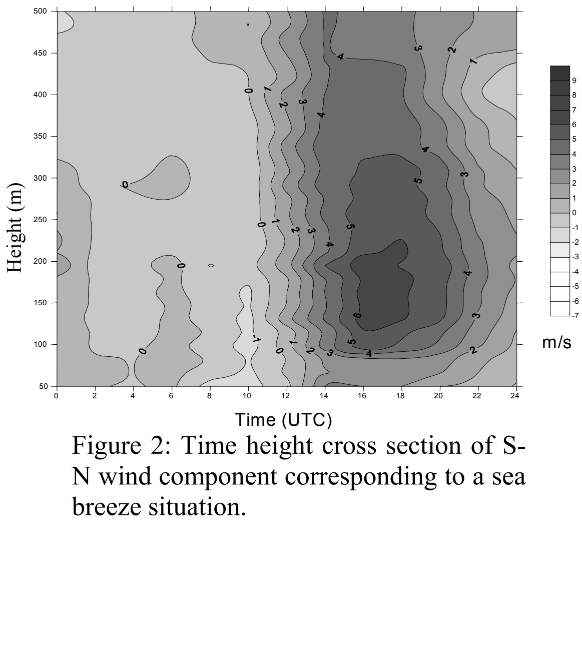

Figure 2: Time height cross section of S-N wind component corresponding to a sea breeze situation.

In order to ensure that the entrance of the sea breeze really takes place through the "Congost", the MM5 model was executed. In figure 3 we can observe the surface wind field at 13 UTC for the smallest domain. The entrance of the sea breeze through the "Congost", which almost reaches the Pre-Pyrenean zone, can be observed. The maximum value of the v-component provided by the model is between 7-8 ms^{-1}. The sea breeze returns at 16 UTC is located at about 1300 m above the measuring place.

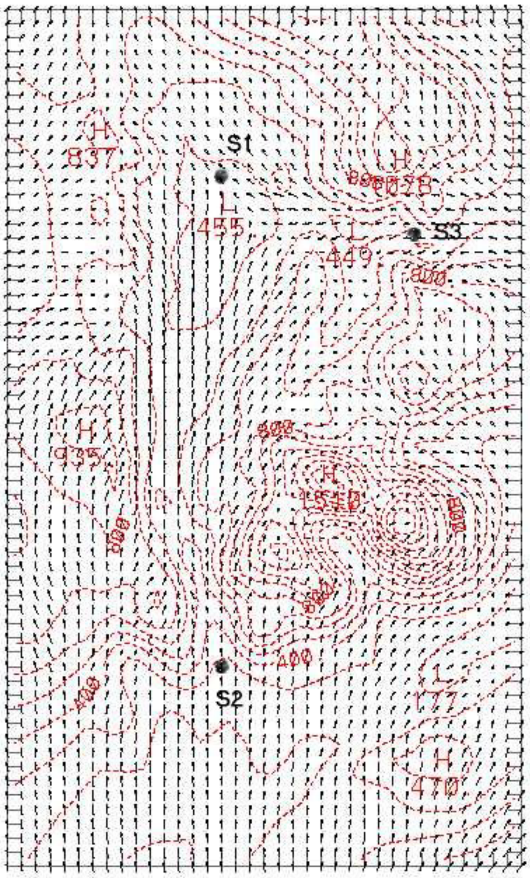

Figure 3. Surface winds vectors at 13:00 UTC and orography. Reference vector : 10 ms^{-1} →

Finally, the model forecasts that the end of the sea breeze is at about 21 UTC. Thus, we can conclude that the results from the model and from the Sodar present good agreement. Moreover, it was observed that surface stations located in "La Plana" also showed wind coming almost from the south sector, from 13 UTC to 21 UTC approximately.

3.2 Drainage and Channelling Winds.

Another very frequent phenomenon (63% of nights observed) is the observed north-westerly drainage winds coming from the Ter valley. These wind regimes take place at night during anticyclonic situations. Basically, two types of regimes can be differentiated:

a) Wind profile with a maximum near 100 m, which is usually formed during the first hours of the night.

b) Wind profile with a singular structure. Presents a calm profile until 100 m and shows a maximum at 200 m approximately. This structure is frequently observed some hours before sunrise.

We believe that this singular profile occurs when nocturnal cooling begins and air masses come down from nearby mountains, (to settle on the denser and colder air masses located in the lowest part of the valley); so the wind maximum is vertically displaced.

In figure 4, an example of each type of profile is shown. In order to obtain more information of this last structure, the time evolution of the echo intensity can be observed in figure 5, for 12 and 13 December 2000. We can observe the beginning of the drainage flow, the echo maximum generated by shear and the decoupling that will be commented below.

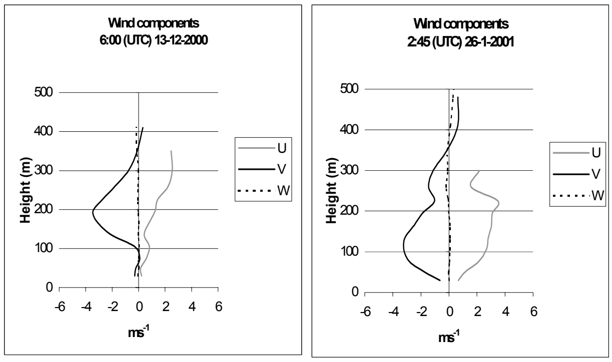

Figure 4. Wind profiles showing maximum intensity at 100 and 200 m respectively.

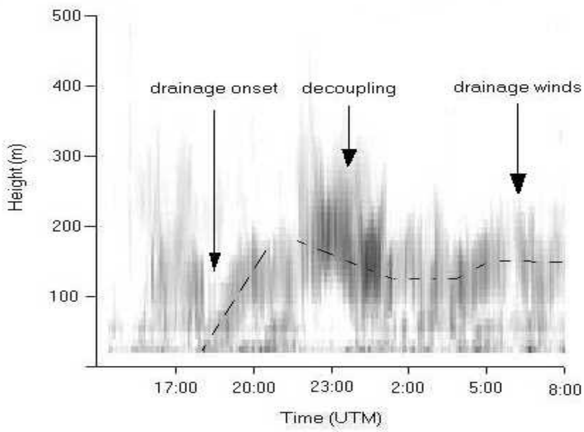

Figure 5. Sodar echo patterns corresponding to different structures.

Another phenomenon, closely related to the second wind profile, which occurs usually in winter, is the decoupling between the air mass inside the valley and the one that come from the higher layers**.** This behavior takes place when, due to the orography, the cooling air remains stagnant in "La Plana" forming a cold air reservoir. Wind profiles show an absolute calm in the first 100 m and a maximum wind higher up; this creates a strong shear which causes a strong echo return at the interfase between these two layers (figure 5). In figure 6, one can observe another wind profile typical of this situation which corresponds to a day when the synoptic pattern indicates winds from a esterly direction. It can be seen that near the surface there is no wind; but it strongly increases with altitude.

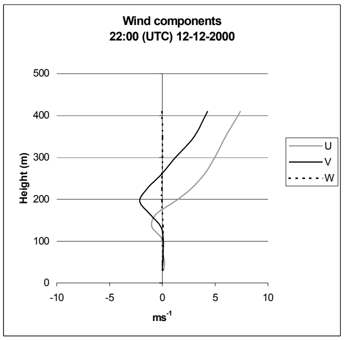

Figure 6. Wind profile showing decoupling.

In addition, the formation of this cold air reservoir favours channelling winds, (Whiteman, 2000). In our case, strong winds from the north and northwest appear at the exit of "La Plana", that is, at "El Congost". They are caused by the Venturi effect, i.e. the cold air mass must flow through the narrow entrance of the "Congost", accelerating in the process and generating very strong winds.

In order to confirm the occurrence of these winds and to measure their intensity and vertical structure, the Sodar was installed near the southern exit (S_2). Winds from the North- West were observed with a maximum speed between 8 and 15 ms^{-1} in the first layer (about 40 m) which decreased slowly until disappearing at about 200 m. In figure 7 one can observe a wind profile corresponding to this situation with winds that reach 10 ms^{-1} in the surface layer. It must be explained that the Sodar was installed on the roof of a building, so we don't have data from the lower layers.

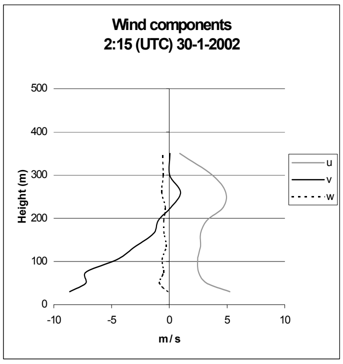

Figure 7. Wind profile at S_2

In the same way as with the sea breeze, a simulation with the MM5 has been set up. The results are shown in figure 8, in which we can see clearly the channelling winds leaving the "Congost "zone near S_2.

4.Conclusions

Measurements of sea breeze, drainage and channelling winds using a Doppler Sodar in complex terrain show its ability to define both the vertical structure and temporal variation of such winds. Otherwise the simulations made with a mesoscale model allowed us to validate the Sodar measurements and to verify the mesoscale structures which usually appears in complex terrain area.

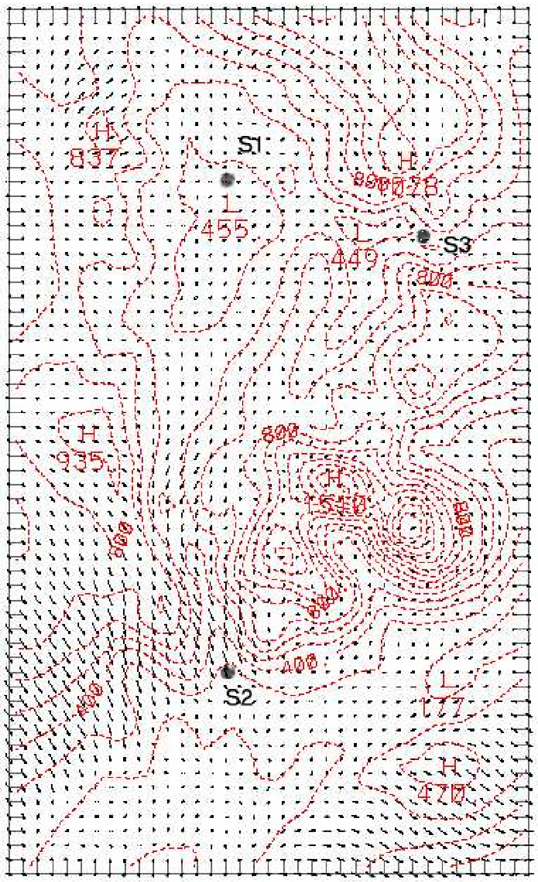

Figure 8. Surface winds vectors at 6:00 UTC and orography Reference vector: 10 ms^{-1} →

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