Atmospheric Research 145–146 (2014) 244–254

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

A study of the nocturnal flows generated in the north side of the Pyrenees

Maria A. Jiménez [a,]*, Joan Cuxart [b]

[a] Department of Global Change Research, Institut Mediterrani d'Estudis Avançats (UIB-CSIC), Esporles, Illes Balears, Spain
[b] Grup de Meteorologia, Departament de Física, Universitat de les Illes Balears, Palma de Mallorca, Illes Balears, Spain

ARTICLE INFO

Article history:
Received 26 February 2014
Received in revised form 11 April 2014
Accepted 21 April 2014
Available online 30 April 2014

Keywords:
Downslope winds
Mesoscale modelling
Mountain-plain winds
Nocturnal boundary layer

ABSTRACT

During night-time, with clear-skies and weak-synoptic pressure gradients, the organization of the flow at lower levels is mainly controlled by the local effects, such as terrain or surface heterogeneities. This is the case of the thermal differences between the air adjacent to the slopes and over the nearby plains that generate downslope winds. The foothills of the north Pyrenees are selected to study the temporal and spatial scales of the downslope winds through a high-resolution mesoscale simulation. From the analysis of the model outputs and the observations, it is found that the organization of the flow at lower levels can be separated in three well-defined regions. At the mountain slopes, downslope winds appear close to the surface whereas down-valley winds form later, after the accumulation of air in the bottom of the valleys due to the downslope winds. At the foothills, the turning of the wind (from upslope to downslope) starts before sunset but it depends on the distance to the Pyrenees, the closer the earlier. Finally, at the Garonne river plain down-river winds are formed at the end of the night, after the accumulation of the downslope winds from the Pyrenees and the Massif Central. Furthermore, the physical mechanisms that take place while the downslope winds travel from the mountain to the plain regions are analysed.

1. Introduction

During night-time and under weak-synoptic pressure gradients, thermally-driven flows are developed over complex topography due to horizontal temperature differences (Whiteman, 2000). Downslope winds are produced by buoyant forces induced by the temperature difference between the air adjacent to the slope and the ambient air outside the slope whereas down-valley winds can be related to the thermal gradient along the valley axis. At a larger scale, the temperature difference between the air in a mountain massif and the air over the surrounding plains generates mountain-plain winds.

Zhong and Whiteman (2008), through mesoscale modelling and observations in the Salt Lake Valley, found that winds at the slopes inside the valley were weaker than downslope winds outside the valley. Stronger winds were found on the gentle slopes than on the steep slopes, similar to the analysis of (Cuxart et al., 2012) in the Ebro basin, whose dimensions are larger than the Salt Lake Valley. From the temperature and momentum budget analysis, Zhong and Whiteman (2008) pointed out that the observed downslope winds were produced by the local cooling of the slope surface. A similar pattern was found by Cuxart et al. (2007) in a quasi-bidimensional gentle slope in the Mallorca Island and by Martínez and Cuxart (2009) in a larger and more heterogeneous slope in the Duero river basin. From tethered balloon soundings, Haiden and Whiteman (2005) showed that the local topography along a gentle slope was the responsible for the along-slope flow variations. Slope winds may interact with lake breezes (Laiti et al., 2013) or with sea

* Corresponding author at: Department of Global Change Research, Institut Mediterrani d'Estudis Avançats (UIB-CSIC), Miquel Marquès 21, 07190-Esporles, Mallorca (Illes Balears), Spain. Tel.: +34 971611868.
E-mail addresses: majimenez@imedea.uib-csic.es (M.A. Jiménez), joan.cuxart@uib.cat (J. Cuxart).

http://dx.doi.org/10.1016/j.atmosres.2014.04.010
0169-8095/

breezes (Cros et al., 2004; Bastin et al., 2005) changing their intensity or the distances they reach.

The area north to the central Pyrenees, in the Garonne basin, is chosen to analyse the different types of downslope and down-valley winds generated within because it is a good example of steep mountain range adjacent to a wide plain area. This basin is limited by the Pyrenees at the south and the Massif Central at the east, and the river flows from south-east to north-west to the Atlantic Ocean (Fig. 1). The influence of the Pyrenees on the atmospheric synoptic flow was analysed in the Pyrenees experiment field campaign (PYREX, (Bougeault et al., 1990)). The dense network of observations at the north and south sides of the Pyrenees during fall 1990 showed that higher and lower pressures at north and south sides of the Pyrenees, respectively, were the responsible of the formation of the three well-known regional wind systems in the area (Bougeault et al., 1997): Autan (south-eastern wind close to Toulouse), Tramontane (north and north-western wind in the Gulf of Lion, (Campins et al., 1995)) and Cierzo (north-western wind in the Ebro river basin, (Masson and Bougeault, 1996)), see locations in Fig. 1. Recently, the Boundary Layer Late Afternoon and Sunset Turbulence (BLLAST) experimental field campaign has been made in Lannemezan (labelled as LZ in Fig. 1), at the foothills of the Pyrenees, during June and July 2011. The aim of this project is to have more and better observations of the late afternoon transition and to further explore the mechanisms that control it. Observations are currently being analysed (Lothon et al., 2010).

The current work is devoted to study the organization of the flow at lower levels under night-time conditions in the northern Pyrenees through the inspection of a high-resolution mesoscale simulation. The main objective is to analyse the relevant factors in the generation of downslope winds and characterise their temporal and spatial scales. The simulated conditions and the model setup are explained in Section 2. In Section 3 the organization of the flow is analysed and Section 4 is devoted to a deeper study of the downslope winds in the foothills region. Finally, the conclusions are given in Section 5.

2. Model setup and description of the simulated conditions

The mesoscale model MesoNH (Lafore et al., 1998) is run with a setup already used in previous studies. For instance, the organization of the flow during the night-time in the Island of Mallorca made by Cuxart et al. (2007), in the Duero river basin as described in Martínez et al. (2010) or, more recently, in a fog case event in the Ebro river basin (Cuxart and Jiménez, 2012). For all the regions studied, the model provides results that compare well to the available observations. A brief description of the model choices is given in Table 1. The horizontal resolution is 2 km × 2 km and covers the Garonne river basin, including the Pyrenees and the west part of the Massif Central. The vertical resolution is fine close to the surface (3 m) and becomes coarser as height increases in order to have a better characterization of the physical

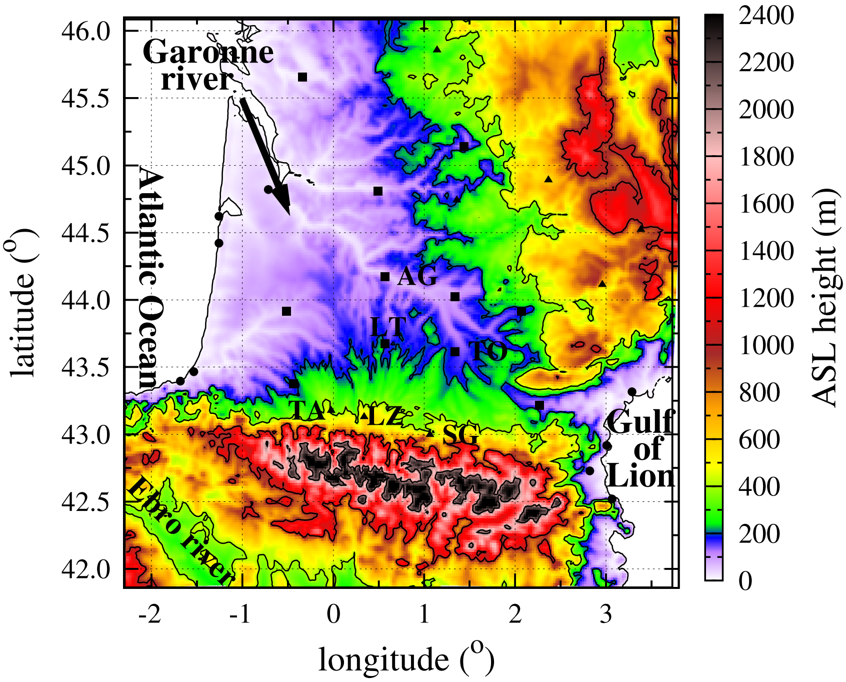

Fig. 1. Simulation domain which covers the Garonne river basin with the Pyrenees at the south and the Massif Central at the east. Topography lines at 200, 400, 1000 and 2000 m (above sea level, ASL) are labelled and in dots there are the locations of the available surface weather stations (in circles the stations at the coast, in squares those at the plain and in white triangles at the foothills). Some of the locations are labelled (SG: Saint Girons, TA: Tarbes and LZ: Lannemezan in the slopes and TO: Toulouse, AG: Agen and LT: Lamonthe in the plain).