



# The role of nocturnal Low-Level-Jet in nocturnal convection and rainfalls in the west Mediterranean coast: the episode of 14 December 2010 in northeast of Iberian Peninsula

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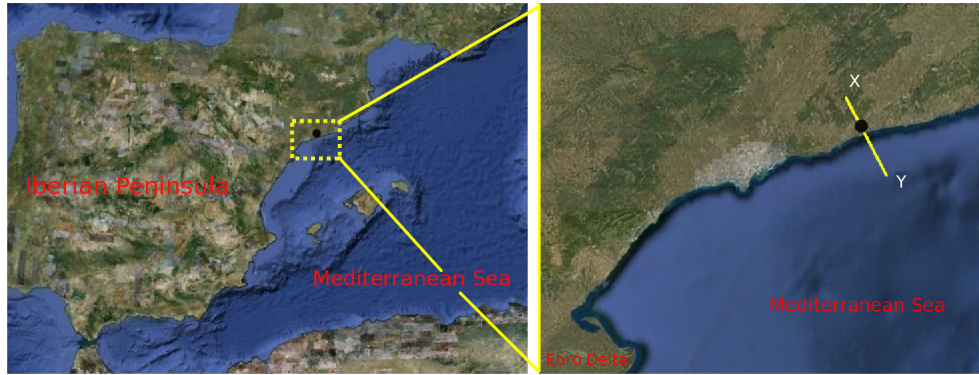
**Abstract.** The night of 14 December 2010 radar images of the Spanish Weather Agency recorded a large rain band that moved offshore at the Northeast coast of the Iberian Peninsula. MM5 mesoscale model is used to study the atmospheric dynamics during that day. A Nocturnal Low Level Jet (NLLJ) generated by an inertial oscillation that brings cold air to the coast from inland has been simulated in the area. This cold air interacts with a warmer air mass some kilometers offshore. According to the MM5 mesoscale model simulation, the cold air enhances upward movements of the warm air producing condensation. Additionally, there is a return flow to the coastline at 600–900 m high. This warm air mass interacts again with the cold air moving downslope, also producing condensation inland. The simulation for the night before this episode shows large drainage winds with a NLLJ profile, but no condensation areas. The night after the 14th the simulation also shows drainage winds but without a NLLJ profile. However, an offshore convergence area was produced with a returned flow, but no condensation inland occurred. This fact is in agreement with radar observations which reported no precipitation for these two days. Consequently, NLLJ in combination with a synoptic wind over the sea could enhance condensation and eventually precipitation rates in the Mediterranean Iberian coast.

## 1 Motivation

Low-Level-Jet (LLJ) is a quite well known phenomenon that has been detected in many areas of the world (Blackadar, 1957; Banta et al., 2002; Stensrud, 1996; Rife et al., 2010). Nocturnal LLJ (NLLJ) is produced by an inertial oscillation (Van de Wiel et al., 2010) over flat terrain in response to a strong radiative cooling and a rapid stabilization of the boundary layer under relatively dry, cloud-free conditions (Blackadar, 1957). Usually NLLJ reaches a peak intensity in the early morning hours, and then decays shortly after dawn, when the convective mixing begins. The wind maximum of a NLLJ develops typically at levels less than 1 km above ground level, and frequently at levels lower than 500 m. As discussed by Stensrud (1996) and Shapiro and Fedorovich (2010), NLLJ exert significant influence on weather and re-

gional climate. It is important to note that these authors affirm that the NLLJ provide dynamical and thermodynamical support for the development of deep convective storms and heavy rain events, besides advection and thermodynamic processes including water vapor (Mahrt et al., 1998; Acevedo and Fitzjarrald, 2001).

Nocturnal Low-Level-Jet is not a typical phenomenon in the Mediterranean coast (Rife et al., 2010). The aim of this work is, by using MM5 mesoscale simulations, to show and describe the role of this NLLJ caused by inertial oscillation detected in one precipitation event observed close to the coastline during the night of 14 December 2010, characterized by its persistence close to the northeastern coast of the Iberian Peninsula (see Fig. 1).



**Figure 1.** The western Mediterranean area (left) and enlargement of the studied region (right). The yellow line marks the cross section where the wind field is analyzed in Sect. 2.

## 2 Analyzed episode: 14 December 2010

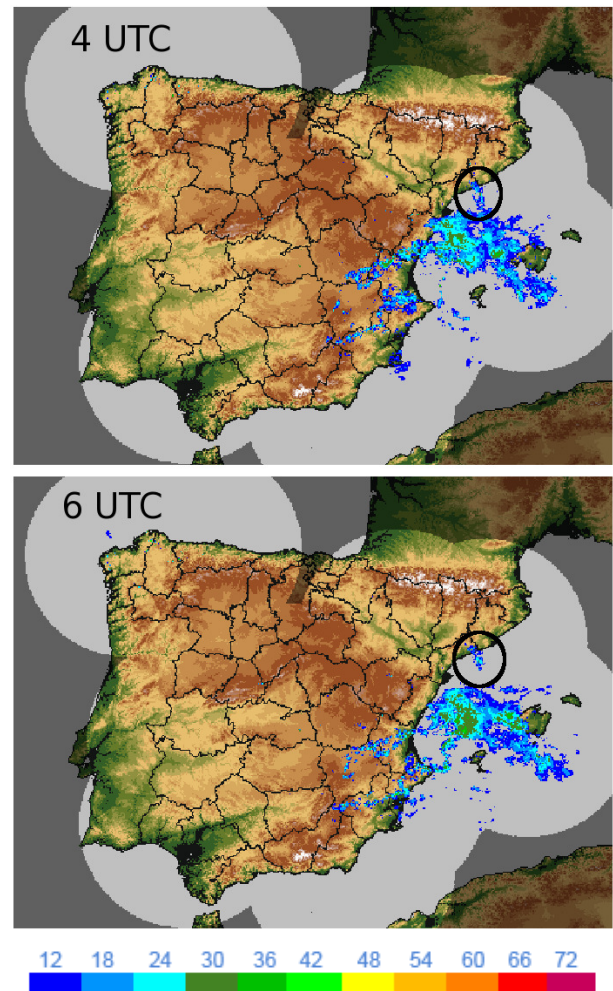
After some days with temperatures between 5 and 10 °C at 850 hPa, during 13 December a high-pressure system placed at the north of UK, and a low-pressure system extended over the Açores islands (not shown) sent cold and dry air mass from northeast to the Iberian Peninsula, cooling the air temperature to  $-5$  to  $-8$  °C at 850 hPa. The night of 13th and the early morning of 14th rainfall was reported in the northeast of Iberian Peninsula. The radar images from the Spanish Weather Agency for 14 December shows a large precipitation area moving offshore. A small precipitation cell close the coast remained for some hours, from 03:00 to 08:00 UTC. Figure 2 show the precipitation pattern at 04:00 and 06:00 UTC. The black circle indicates the stationary precipitation cell.

The hypothesis proposed here is that such precipitation was caused by the interaction between a cold air mass moving offshore with a LLJ profile and a warmer air mass associated to synoptic winds.

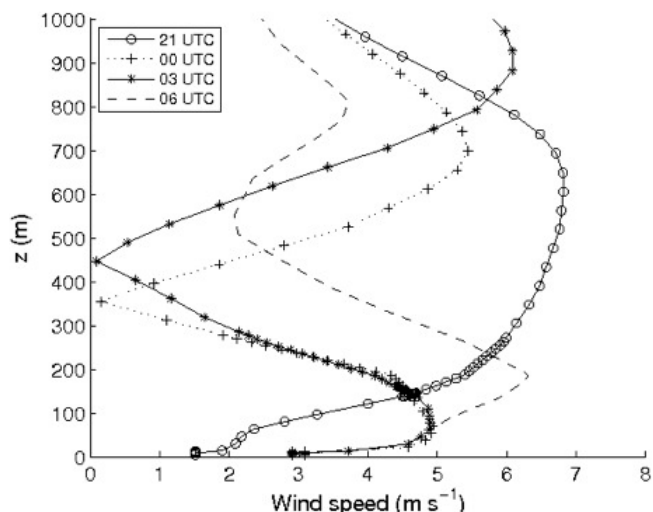
Different wind patterns have been simulated during 13 and 15 December and no precipitation was recorded. Our aim in this work is to analyze the atmospheric dynamics of these three days to study the possible cause of the different precipitation records.

### MM5 numerical simulation

The three studied days were simulated by using 5th generation of the PSU/NCAR mesoscale model (MM5, Grell et al., 1995). The simulation setup was as follows. Four nested domains with resolution of 27, 9, 3 and 1 km working in two-way nesting option were defined. The smallest domain is focused on our interested area (see Fig. 1). *Kain-Fritsch* scheme for cumulus (none in the two smallest domains), *Simple Ice* for explicit moisture scheme and *MRF* for the planetary boundary layer parametrization were used. The initial and boundary conditions were updated every six-hours with



**Figure 2.** PPI radar reflectivity (in dB) from Spanish Weather Agency at 04:00 and 06:00 UTC on 14 December 2010. The black circle indicates the rainfall area studied.

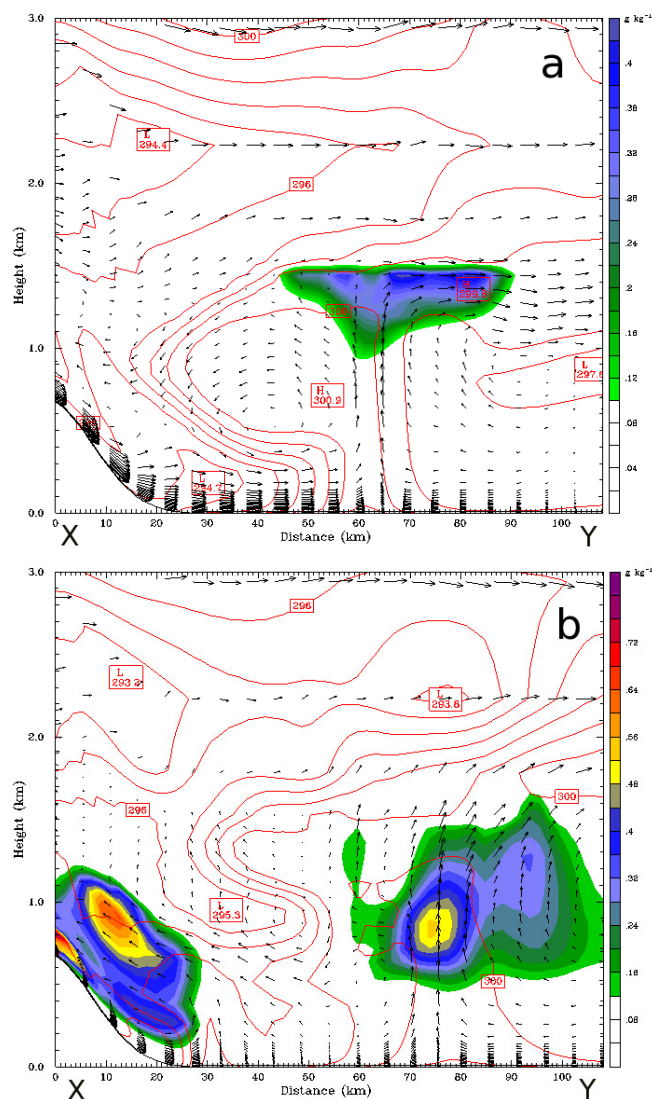


**Figure 3.** Simulated vertical wind profile at different hours during the night of 13th and early morning of 14th at the point marked by a black dot in Fig. 1.

information obtained from the ECMWF analysis model. The model simulation ran during 90 h starting at 00:00 UTC on 12 December 2010. The night of 13th and early morning of 14th a NLLJ appeared as can be observed in Fig. 3. This figure shows the temporal evolution of the simulated wind speed vertical profile at a point marked by a black dot in Fig. 1. At 21:00 UTC of 13th the wind speed increased in height. At 00:00 UTC of 14th the maximum wind speed was located around 100 m high, with values of  $5 \text{ m s}^{-1}$ . Until 06:00 UTC the maximum velocity of the NLLJ increases, being at this time  $6.4 \text{ m s}^{-1}$  and located around 200 m high. The hodograph (not shown) confirms that the wind speed profile is a NLLJ, due to an inertial oscillation.

Figure 4 shows the vertical cross section along the yellow line shown in Fig. 1 of the simulated wind field (arrows), equivalent potential temperature (red contour lines) and cloud mixing ratio (colored contour,  $q_{cl}$ ) at 00:00 (a) and 03:00 UTC (b). It is interesting to note the two condensation areas produced by the simulation in Fig. 4b. One is located offshore, around 65 km far away from the coast and appeared early that night. The second condensation area is located inland, and appeared later. This area of cloudiness is produced at 600–900 m high by the interaction of the return flow that brings warm and moist air inland with the cold air mass moving downslope. The equivalent potential temperature (red lines) is larger in the condensation areas due to a relative warm and moist air mass advection from the sea. Note that in the offshore convection area a larger value of equivalent potential temperature extends vertically, and to the coastline.

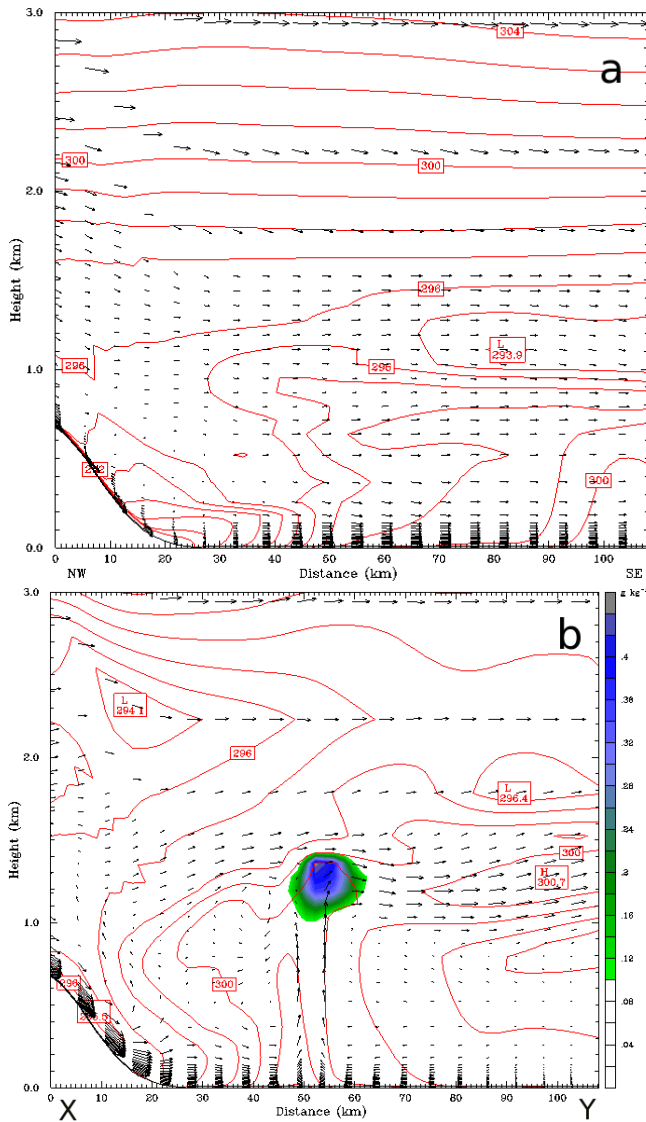
These two simulated areas with  $q_{cl} > 0$  approximately corresponds to the precipitation areas observed by the radar images indicated by a black circle in Fig. 2. Moreover, the sim-



**Figure 4.** Vertical cross sections along the yellow line of Fig. 1 of the wind (arrows), equivalent potential temperature (red contour lines) and cloud mixing ratio (colored contour) at 00:00 (a) and 03:00 UTC (b) on 14 December 2010. The maximum wind speed is  $9.5 \text{ m s}^{-1}$  approximately.

ulated hourly accumulated precipitation (not shown) has a good correspondence with the precipitation pattern observed in radar images inside the black circle shown in Fig. 2 but the precipitation rates are underestimated. Eventually, the offshore convergence area moved to the coast and the two precipitations areas shown in Fig. 4b joined forming only one area of precipitation from 04:00 to 08:00 UTC (not shown).

The NLLJ drives cold inland air to the coastline. The relative warm and wet air returned to the coast and condensates when interacts with the cold inland air. According to Fig. 3, at early morning the wind speed presented a maximum value, coinciding with an increase of cloud mixing ratio at the mountain slope (not shown). The vertical and temporal



**Figure 5.** Simulated vertical cross sections along the yellow line of Fig. 1 of the wind field (arrows), equivalent potential temperature (red lines) and cloud mixing ratio (color contour) at 04:00 UTC on (a) 13 December and (b) 15 December. The maximum wind speed is  $8.1 \text{ m s}^{-1}$  and  $6.5 \text{ m s}^{-1}$  in the upper and lower panels, respectively.

evolution of potential temperature has also been analyzed (not shown). The minimum values appear between 00:00 and 01:00 UTC on 14th, with 280.5 K at low levels, below 150 m high, where the wind speed has the maximum values. Above these levels the potential temperature increases 4 K and remains constant at the upper levels. At early morning the potential temperature has a constant value with height of 283 K.

In order to analyze the role of the NLLJ and the return flow on the condensation process inland, the wind field, equivalent potential temperature and cloud mixing ratio obtained with

**Table 1.** Relation between the atmospheric conditions according MM5 simulation and radar observation.

Night	Sim. div < 0	Sim. Rotor	Sim. NLLJ	Sim. $q_{cl} > 0$	Radar precip.
13th	weak	No	Yes	No	No
14th	Yes	Yes	Yes	Yes	Yes
15th	Yes	Yes	No	No	No

the MM5 simulation for the previous night (13 December) are shown in Fig. 5a. A NLLJ appear at the same place during several hours but not a convergence area offshore because the synoptic wind blows in the same direction. Thus, there is not return flow and condensation inland. The simulated wind field, equivalent potential temperature and cloud mixing ratio for 15 December are shown in Fig. 5b. During this day it is possible to observe downslope winds (in this case without a LLJ profile) and a convergence area about 50 km offshore. A return flow appeared, but there is no condensation inland because the downslope air has an equivalent potential temperature 4 K larger than the air on 14 December.

In order to compare the differences in wind configuration during 13, 14 and 15 December 2010, Table 1 shows the main characteristics obtained from the MM5 simulation and the radar images.

### 3 Summary and conclusions

Analyzing the radar images during the night of 14 December 2010, we have observed a static precipitation area close to the coastline in the Northeast of Iberian Peninsula. By using MM5 simulation, two different condensation areas have been identified: the first one due to offshore convergence and the second one inland, associated with the interaction between the cold air driven by a NLLJ with the wet air that returns aloft to the coastline. These simulated condensation areas approximately correspond to the precipitation areas observed by the radar images in this area, at the same hours.

By comparing the simulation of the 14th and 15th nights, it can be concluded that when the air advected by the NLLJ is not enough cold, condensation inland is not produced. By comparing the episode on 14 December with the previous night (13 December), a NLLJ appears in both simulations but no offshore convergence during 13 December because the synoptic wind flew in the direction of the drainage winds. Consequently, there is not return flow of wet air to the coast and no condensation inland.

Summarizing, the appearance of a NLLJ that brings cold air to the coast combined with a synoptic offshore wind could enhance not only convergence and precipitation over the sea but also inland precipitation due to the interaction of the NLLJ with the return flow.

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