Tethys, 3, 67–73, 2006
www.tethys.cat
ISSN-1139-3394
DOI:10.3369/tethys.2006.3.09

Journal edited by **ACAM**
(Associació Catalana de Meteorologia)

Local nocturnal circulations in the island of Majorca: mesoscale modelling and verification

M.A. Jiménez, J. Cuxart, A. Mira, and D. Martínez

Grup de Meteorologia, Departament de Física, Universitat de les Illes Balears

Received: 18-X-2006 – Accepted: 3-XII-2006 – **Original version**

Correspondence to: mantonia.jimenez@uib.es

Abstract

A mesoscale simulation for the island of Majorca in the Western Mediterranean Sea is used to study the nocturnal system of winds under weak synoptic pressure gradients. A very high vertical resolution is used in the first 500 meters above ground level to characterize with large detail the thin circulations close to ground, namely basin and katabatic flows. It is found that the island, the basin and the slope scales interact strongly, especially when a quasi-steady state is reached in the second part of the night. A high mountain range creates a high pressure area upwind where local winds can develop. Katabatic flows converge to the valleys, where they interact with a cold pool, which is advected slowly to sea by the land-sea night-breeze effect combined with a topographic forcing. To see how realistic is this run, the outputs are compared against available observations: data from Automatic Weather Stations and satellite images. Although verification is a difficult task, the modelled patterns of wind and temperature agree with the observed ones.

1 Introduction

When a region is under slack synoptic-scale pressure gradients, the local meteorology is largely determined by the heterogeneities at the surface. The night-time spatial structure and temporal evolution are far from stationary or homogeneous, especially in stably stratified conditions. Under these conditions, specially with light synoptic winds and clear skies the role of the topography becomes extremely important. Cold pools form in the center of the basins, and outvalley circulations, slope flows or other kinds of low-level jets are present. All these features affect the local climate. To determine their spatial structure and temporal evolution is crucial to understand the air circulations within a basin.

The island of Majorca (Figure 1) has a characteristic size of 100 km, a large mountain range at its northwestern side (Serra de Tramuntana), with an average height of 700 m above-sea-level (ASL) and the central part has several peaks between 1000 and 1450 m. On the opposite side (SE) there is a discontinuous lower mountain range (Serra de Llevant), with an average height of 300 m, that perturbs much less the flow than the Serra de Tramuntana. The center of the island is relatively flat, although elevated about 200 m ASL and with a small central mountain (Randa, 500 m). This topographical configuration results in three main basins: the Palma basin at the SW part, the Campos basin at the SE, the Alcudia basin at the N, plus two coastal narrow basins between the mountain ranges and the sea at NW and E.

To check whether the simulations are realistic, the outputs are compared to three types of data:

- Automatic Weather Station (AWS): 10 AWS from INM (Institut Nacional de Meteorologia) that provide 10 m wind and direction and 2 m-temperature and humidity, plus precipitation and pressure at the surface.
- NOAA (National Oceanic and Atmospheric Administration) imaginery: On average, there are two NOAA images per night, with a horizontal resolution close to one km at nadir. The field used is the radiometric surface temperature, which is obtained after some corrections (radiometric, geometric and atmospheric -water vapour-).
- METEOSAT Second Generation (MSG-1) imaginery: This satellite produces one image every 15 minutes, but its horizontal resolution is about 4 km for Majorca. They are used to produce temporal series for selected pixels to compare to AWS series and grid-point model outputs.

Table 1. Summary of the setup of the run.

Domains	2, two-way nested
Inner domain	125 km × 100 km
Outer domain	480 km × 320 km
Horizontal Resolution	5 km (outer domain), 1 km (inner domain)
Vertical resolution	near the ground: Δz = 3 m;
	at z = 500 m: Δz = 7 m;
	top of the domain: Δz = 600 m
Equation system	Durran (1989)
Lateral boundary conditions	Analysis from the ECMWF every 6 hours
Radiation scheme	Morcrette (1990)
Advection Scheme	Flux corrected second order centered
Turbulence Scheme	1-Dimensional TKE scheme: Cuxart et al. (2000)
	Mixing length: Bougeault and Lacarrère (1989)
Soil Scheme	ISBA (Noilhan and Planton, 1989)
	Cover types: CORINE (Heymann et al., 1994)
	z_0 (sea and inland waters): Charnock (1955)
	z_0 (artificial areas): Masson (2000)

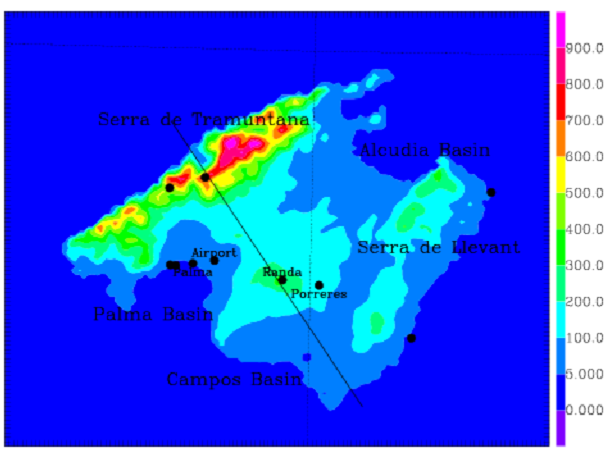

Figure 1. The inner domain (with a length size of 125 km × 100 km in the x and y directions, respectively) of the run corresponding to the island of Majorca, with the three well defined basins: Palma, Alcudia and Campos. The line corresponds to a cross-section in a further figure and points to the Automatic Weather Stations.

2 Description of the case and model setup

To perform this study, the Meso-NH model of the French community has been used (Lafore et al., 1998). The model can be used in a large variety of configurations (from Large-Eddy Simulations (LES) to synoptic scales). Its performance for several boundary layer regimes has been tested successfully (Cuxart et al., 2000) and the nocturnal stable boundary layer has received special attention lately (Jiménez and Cuxart, 2005; Cuxart and Jiménez, 2007).

A case with a slack synoptic pressure gradient is chosen; the archipelago is very close to the center of a winter high pressure system, with the flow coming from the southeast (of about 4 m s^{-1} over the sea at 10 m ASL), thus normal to the main mountain range at the NW. This is a typical winter high-pressure situation with weak large-scale winds for this area. The skies were cloudless and the humidity was low (below 30% at the beginning of the night). This synoptic situation was steady during that night.

Two nested domains are chosen. The largest one covers the Balearics with a resolution of 5 km, and the inner one of 1 km covers only Majorca. The lateral boundary conditions are provided by the European Centre of Medium-range Weather Forecasts (ECMWF) analyses. The resolution of 1 km is thought to be sufficient to capture most of the almost horizontal advective transport in the lower layers, fitting well with the resolution of the available physiographical data sets and avoiding the use of the computationally expensive three-dimensional turbulence scheme.

The simulation runs from 12 UTC (12 local solar time) on January 5th, 1999 to the dawn of the next day. The vertical resolution is very fine near the ground (3 m), to be able to capture all the details of the low level flows. Such a fine vertical resolution implies very short timesteps (below 2 s), especially at mountain slopes. Since such a simulation depends very much on the physiographical and the physics packages, its realism will depend very much on the good work of the schemes of turbulence (Cuxart et al., 2000), radiation (Morcrette, 1990) and soil-vegetation (Noilhan and Planton, 1989), together with a good representation of the terrain physiography. Further details of the setup of the run are found in Table 1.

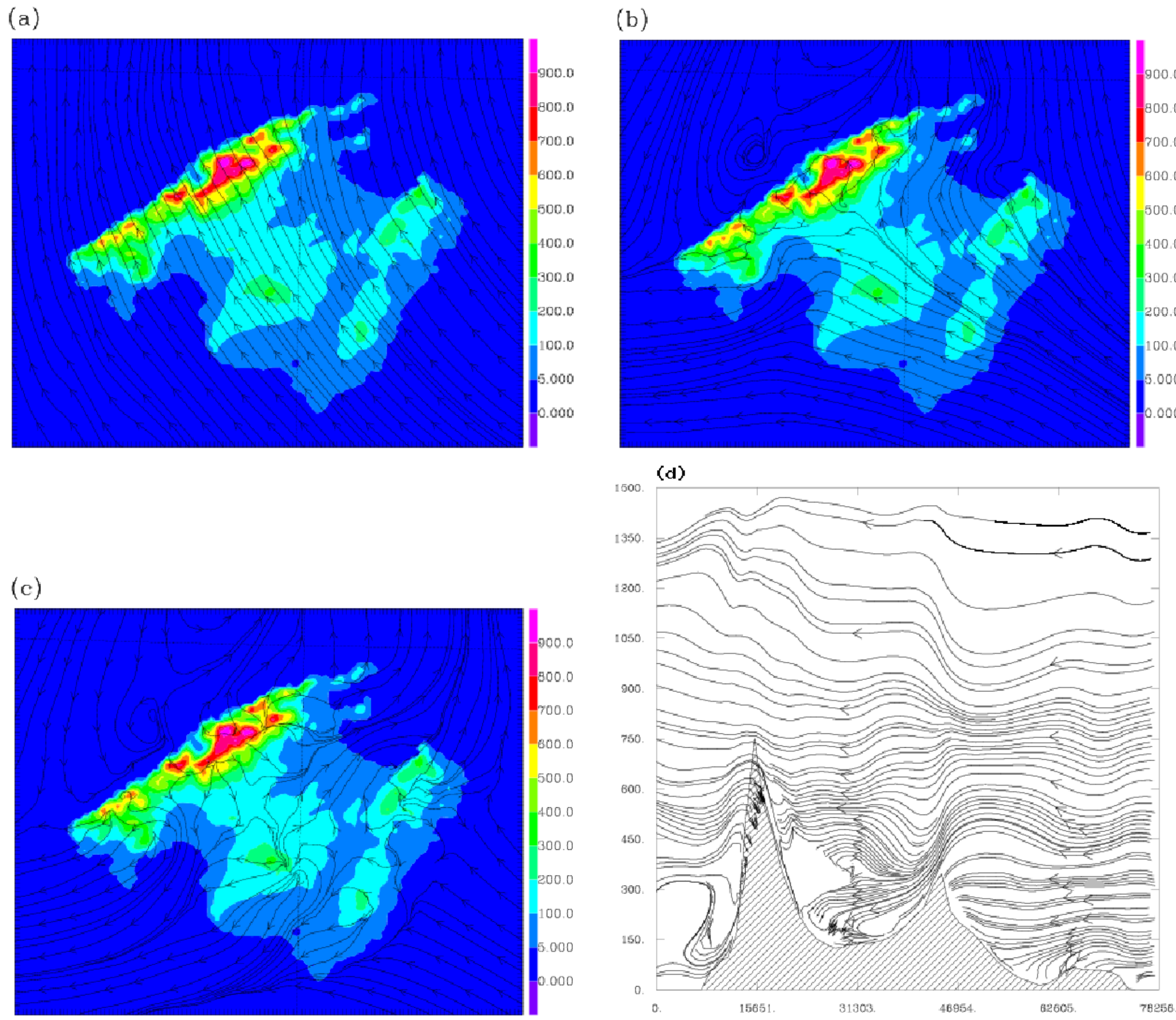

Figure 2. Stream lines at 04 UTC at different heights: (a) 1000 m; (b) 100 m and (c) 10 m. In (d) there is the vertical stream lines following the line in Figure 1.

3 The interaction of the island with the general flow

Here only plots of the inner domain at 04 UTC will be shown, considered a time representative of the quasi-steady state situation of the second part of the night. The streamlines at 04 UTC show (Figure 1.a), that the flow is not perturbed very much as it flows over the island at a height of 1000 m above the ground. However at 100 m (Figure 2.b), the NW mountain range (Serra de Tramuntana) is clearly blocking and diverting the flow around it, with a bifurcation point near the centre of the island. A low pressure area is found downwind of the main range, marked by an eddy, whereas upwind there is a mesobeta high pressure area (not shown). Therefore the center of the island is an area of low wind speeds and is able to develop local winds determined by the topographical configuration.

The exploration of the vertical cross section in the NW - SE direction (Figure 2.d) indicates that the topographic obstacles perturb the flow for several hundreds of meters above the ground in the case of the Randa mountain, and for several thousands of meters in the case of the Tramuntana range, developing stationary waves above them. The same figure shows that the areas between the mountains have structures determined by the shape of the basins, with wind directions mainly determined by the mountain slopes, and vertical extension between 100 and 250 m above the ground.

The organization of these low-level structures is mainly found to be by topographical basins (Figure 2.c). The streamlines at 10 m show that the air is flowing from the center of the island to the sea in the three main basins (Palma, Alcudia and Campos). The Llevant mountain range, despite of its modest vertical height, is able to produce land-to-sea winds strong enough to stop the progression inland of the

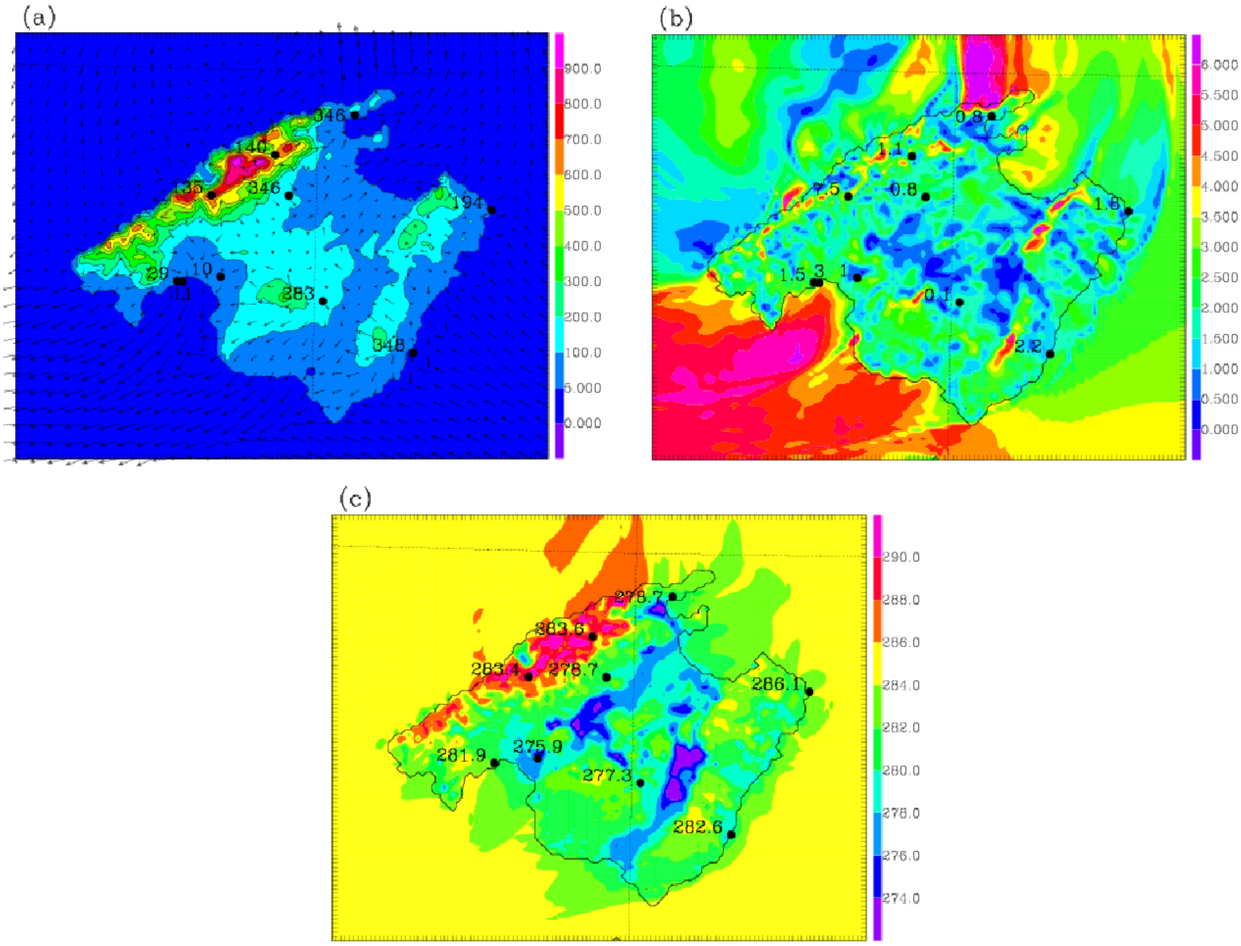

Figure 3. Horizontal cross-sections at 04 UTC for (a) wind direction (in degrees) at 10 m, (b) wind speed (in m s^{-1}) at 10 m and (c) potential temperature (in K) at 1.5 m. The surface weather stations are indicated with a point with the observed value aside. In (a) only one arrow every 3 grid points is drawn.

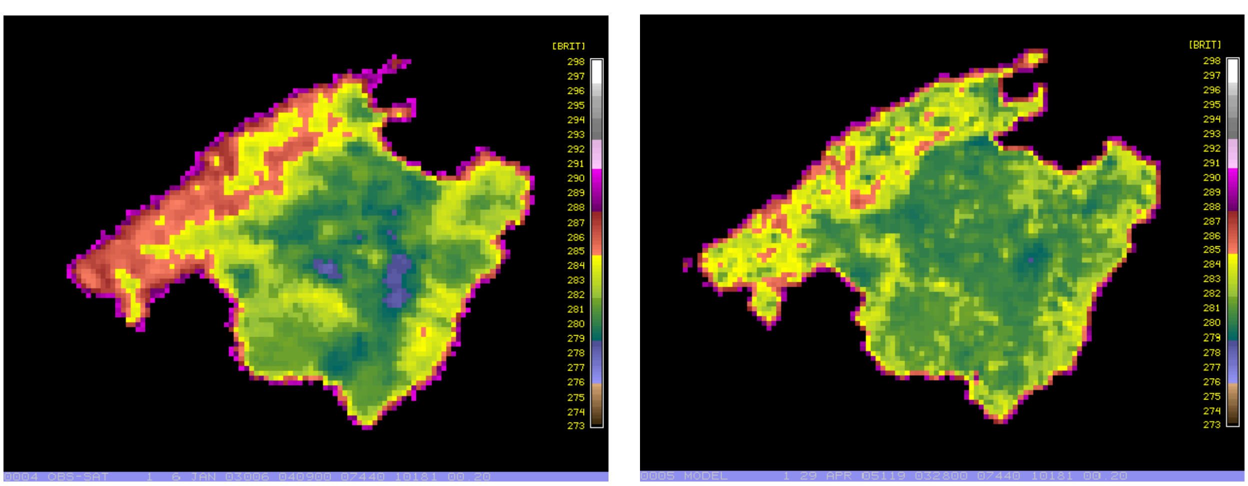

Figure 4. (a) (Left fig.) Surface radiative temperature calculated from the NOAA satellite image at 03:28 UTC on 29/04/05; (b) (right fig.) the same calculated from the model at 03:30 UTC. Further description of this case in Mira et al. (2006).

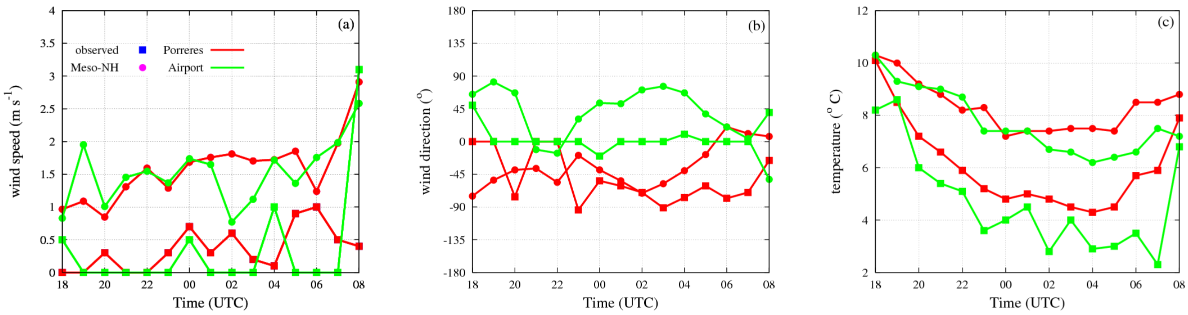

Figure 5. Modeled and observed time series for (a) wind speed (in m s^{-1}), (b) wind direction (in degrees where the north corresponds to 0°) and (c) temperature (in °C) at Porreres and the Airport (see the locations in Figure 1), corresponding to an inland and a coast sites, respectively.

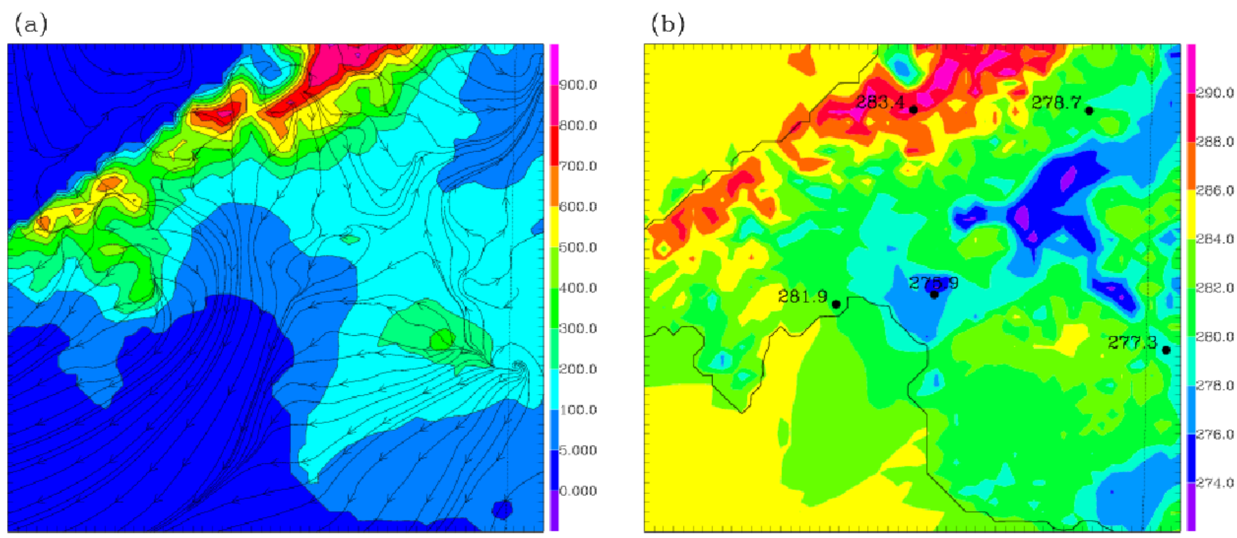

Figure 6. (a) Stream lines at 10 m and (b) potential temperature at 1.5 m at 04 UTC in the Palma basin. In points there are the observations of the surface weather stations.

general flow from the SE and is a key factor to shelter the center of the island and allow the development of local structures there. Within each basin, there is convergence in the center and maximum outland wind speeds flowing over the warmer sea where they become thermally unstable and finally lose identity.

This organization is also shown in Figure 3, where the values observed by the AWS are plotted over the modeled fields. The direction and the wind speed (Figures 3.a and 3.b) are well captured except in a sheltered station at the north of the island. The existence of areas with very weak winds at 10 m is confirmed, although the number of inland stations is very low. The areas of lowest temperature are located in the center of the island where the wind is almost calm. The 1.5 m-temperature field has spatial patterns similar to the ones shown by the NOAA image (see Figure 4, corresponding to a different case with similar conditions -clear sky, weak wind for 29/04/05- further described in Mira et al. (2006).

To evaluate if the time evolution is well captured, the observed and modeled timeseries for some stations are compared (Figure 5). In Porreres, located at the east foothill of the Randa range in the flat central part of the island, the observations show almost calm wind for most part of the night. The AWS have an estimated threshold value of, at least, 0.5 m s^{-1}. The model generates winds larger for this location of about 1 m s^{-1}, with a good approximation to the wind direction. The temperature drop is larger in the observations. The very weak observed real wind allows the surface to cool radiatively practically without shear-generated turbulence present. Since the model has larger wind, it has enhanced shear and mixing in the surface layer, therefore allowing for a less intense near-the-surface cooling.

4 Circulations in the mesobeta Palma basin

The Palma basin has the approximate shape of a semicircle with a radius of about 20 km, opening to the sea at the SSW at the Palma bay. Three different types of terrain surround the almost flat central part of the basin, of about 10 km of radius. At the W and NW the very steep Tramuntana range is composed by a number of narrow valleys where the mountains top at about 1000 m and the bottom parts are at about 200 m ASL. Each valley has its own dynamics and generates outvalley flows during the night-time (Whiteman, 1990) towards the center of the basin. The model smoothes these features and consequently the generated circulations, but the overall behavior is captured as the comparison of the wind with the observations shows.

At the N side of the basin, the Tramuntana range is more like a high wall dropping from 1100 to 250 m ASL in 4 km. The model topography has a resolution of 1 km, and underestimates the height of the range. At the E part, the basin is closed by a quasi bi-dimensional slope of a length of about 10 km that extends some 15 km inland. This slope has at the top in the central part the circular-shaped Randa mountain (500 m ASL). This slope is well represented by the model topography. Each of these three well defined structures generates katabatic winds that converge in the flat part of the basin (Figure 6.a).

The 1.5 m-temperature field at 04 UTC (Figure 6.b) has the minimum values in the center of the basin, right in the area where the airport is located. The AWS observed temperatures plotted on the figure show that the pattern is well captured. The evolution of the wind and temperature for the airport (Figure 5) indicates that, again, the model tends to slightly overestimate the wind in the central part of the basin. The modeled values are between 1 and 2 m s^{-1} compared to the observed values that are between calm and 1 m s^{-1}, a difference that can as well explain why the observed drop of temperature is 3 degrees larger than the modeled one.

The W and NW parts seem to contribute as outvalley flows, whereas the rest of the topography acts as a generator of katabatic flows. The ensemble of flows converge at the center of the basin, where the cold air accumulates and is impelled to the sea driven by the pressure gradient that results from the warmer air above the water in the Palma bay. Time series shown in Figure 7 show a good agreement between model and data.

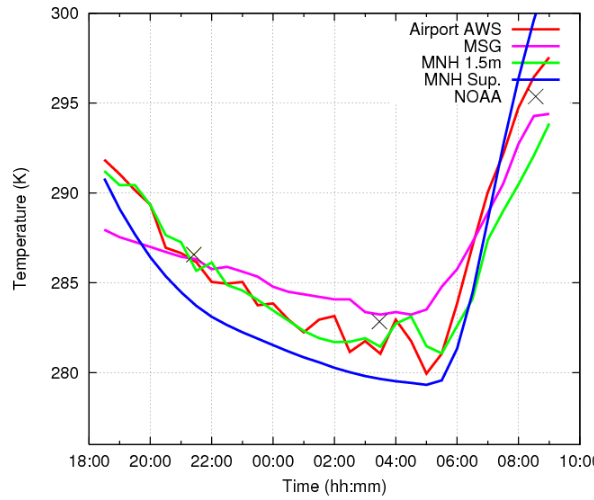

Figure 7. Time series during the night on 29/04/05 between 18 UTC and 09 UTC in the Airport in the Majorca Island (see location in Figure 1). The 1.5 m temperature obtained from the model is compared to the one measured from the AWS and the radiative temperature obtained from MSG-1 and NOAA images.

5 Conclusions

Despite its relatively small size, Majorca has a complicated flow pattern in the night-time, mostly related to its topographical characteristics. When the synoptic wind is weak, the island becomes an area where locally generated winds prevail. The mesoscale simulation, performed at a very high vertical resolution, allows to inspect many details of the low level flows. It is found that the different relevant scales (island, basin and slope) generate flows that interact in a complex manner.

The Tramuntana mountain range allows the creation of a zone of very weak winds over the centre of the island, and outland flows at its sides. Inland, the calm wind areas in clear-sky conditions, allow for the development of slope flows and of cold pools in the valleys, that will interact as the night advances. The land-sea breeze effect, due to a relatively warm sea surrounding the island, introduces a component outland from the island. Once these features are set, at about 5 hour after the sunset, the patterns are almost stationary. The comparison with available data and satellite imagery gives support to the picture obtained from the simulation.

Acknowledgements. This work has been partially funded by the research project REN2003-09435/CLI of the Spanish Ministry of Research, and by a Special Project of the Governement of the Balearic Islands. The ECMWF is acknowledged for the computing time and the users support, and the INM for the data of the AWS.

References

Bougeault, P. and Lacarrère, P., 1989: *Parameterization of orographyinduced turbulence in a mesobeta scale model*, Mon. Weather Rev., **117**, 1872–1890.

Charnock, H., 1955: *Wind stress in a water surface*, Q. J. Roy. Meteorol. Society, **81**, 639–640.

Cuxart, J. and Jiménez, M., 2007: *Mixing processes in a nocturnal Low-Level Jet: An LES study*, J. Atmos. Sci., **64**, 1666–1679.

Cuxart, J., Bougeault, P., and Redelsperger, J.-L., 2000: *A turbulence scheme allowing for mesoscale and large-eddy simulations*, Q. J. Roy. Meteorol. Society, **126**, 1–30.

Durran, D. R., 1989: *Improving the anelastic approximation*, J. Atmos. Sci., **46**, 1453–1461.

Heymann, Y., Steenmans, C., Croissille, G., and Bossard, M., 1994: Corine land-cover - Technical guide, vol. Luxembourg, Office for Official Publications of the European Communities.

Jiménez, M. A. and Cuxart, J., 2005: *Large-eddy Simulations of the Stable Boundary Layer using the standard Kolmogorov theory: range of applicability*, Bound.- Lay. Meteorol., **115**, 241–261.

Lafore, J. P., Stein, J., Asencio, N., Bougeault, P., Ducrocq, V., Duron, J., Fisher, C., Héreil, P., Mascart, P., Pinty, J. P., Redelsperger, J.-L., Richard, E., and de Arellano, J. V.-G., 1998: *The Meso-NH atmospheric simulation system. Part I: Adiabatic formulation and control simulation*, Ann. Geophys., **16**, 90–109.

Masson, V., 2000: *A physically based scheme for the urban energy budget in atmospheric models*, Bound.- Lay. Meteorol., **94**, 357–397.

Mira, A., Cuxart, J., Jiménez, M. A., Luque, A., Alonso, S., and Guijarro, J., 2006: *Verification of a clear-sky mesoscale simulation using satellite-derived surface temperatures*, J. Appl. Meteor. Clim., **Submitted**.

Morcrette, J.-J., 1990: *Impact of changes to the radiation transfer parameterizations plus cloud optical properties in the ECMWF model*, Mon. Weather Rev., **118**, 847–873.

Noilhan, J. and Planton, S., 1989: *A simple parameterization of land surface processes for meteorological models*, Mon. Weather Rev., **117**, 536–549.

Whiteman, C. D., 1990: Observations of thermally developed wind systems in mountainous terrain, vol. 23, Atmospheric Processes over Complex Terrain, Meteor. Monogr., Amer. Meteor. Soc.