SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	THE ROLE OF BASIN TOPOGRAPHY AND SURFACE HETEROGENEITIES IN THE ORGANIZATION OF THE FLOW AT LOW LEVELS
Computer Project Account:	spesturb
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Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Other Researchers (Name/Affiliation):	Joan Cuxart Rodamilans (UIB) Daniel Martínez Villagrassa (UIB)

Summary of project objectives

(10 lines max)

The aim of the special project is to increase the current knowledge of the processes in the surface-atmosphere interface through a combined inspection of simulations and observations from the campaigns in which we participate. Firstly, the interactions between heterogeneous surfaces and the atmosphere will be explored through simulations based on observational campaigns held in the Eastern Ebro valley in zones with extensive irrigated areas, linked to the LIAISE effort from HyMeX. Secondly, we will continue exploring the organization of the wind at low levels in the island of Mallorca under Sea-and Land-Breeze conditions. A combined inspection of mesoscale simulations and observations from an experimental field campaign (continuous measurements started in January 2021) will be used to understand the interaction between the sea and land breezes and local winds (slope winds) and other winds from larger scales.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

None

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The organization of the special projects application is clear and adequate. Besides, it is important to mention the kind help from the user support service, especially important in the upgrades.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

As it is stated in the objectives of this project, simulations over two different complex terrain regions are performed. Firstly, the runs over the Ebro river basin are explained and afterwards the attention is focused on the island of Mallorca (western Mediterranean Sea).

1. Exploring the circulations at lower levels in a complex river basin (surface and topography).

The period 16 – 18 July 2016 was taken to perform the 1st intercomparison exercise (launched during the preparation of the LIAISE campaign) because it is close to the period in the year when the LIAISE campaign took place (July 2021). During this time interval, the eastern Ebro river subbasin was under the influence of a high-pressure system centered in the NW France and thermally-driven circulations were developed in the region of interest (close to Mollerussa, a dot in Figure 1) and also in coastal areas where sea/land breezes were present. There are 3 participating models: MesoNH, WRF and UK Unified Model. All models are run with the same horizontal (see Figure 1) and vertical (2m close to the surface at stretched above) resolutions. Initial and lateral boundary conditions are taken from the ECMWF analysis. Sensitivity tests are also performed to quantify the impact of some model options such as the horizontal resolution, the initial/boundary conditions, the processes described in the surface package of the model and the physiographical features of the surface.

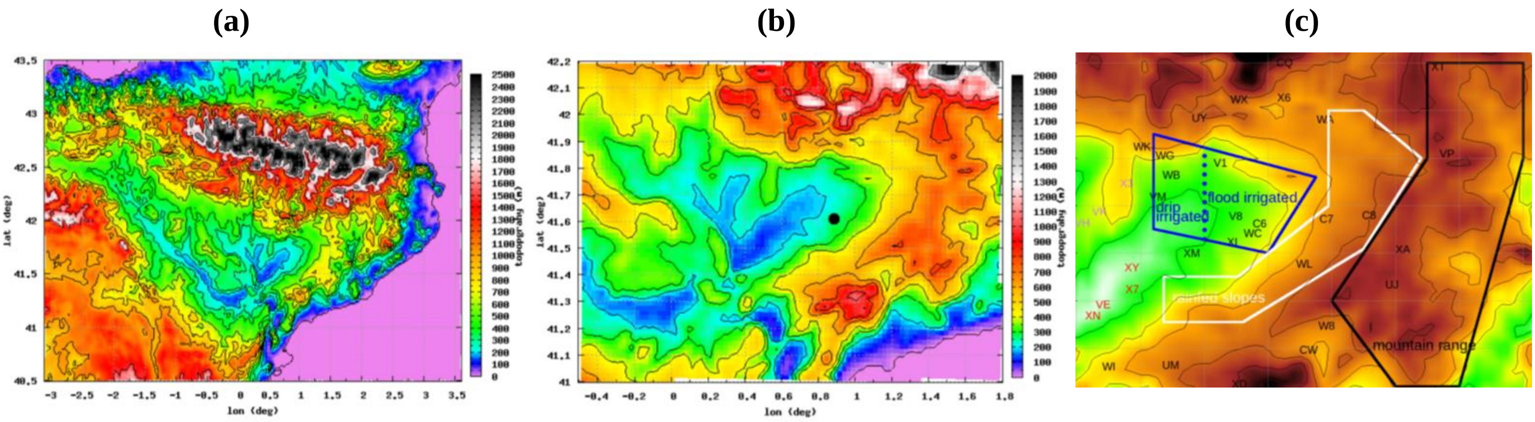
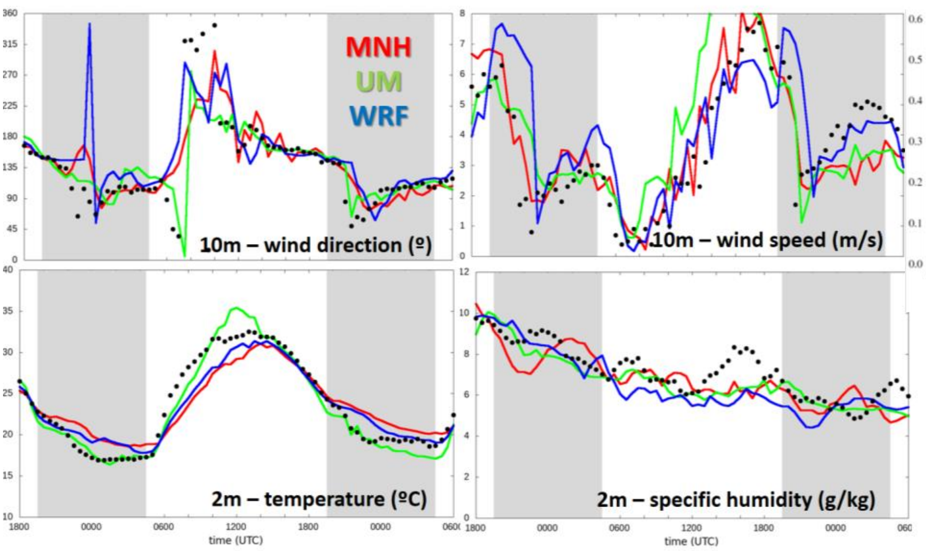


Figure 1. (a) Outer (2km x 2km) and (b) inner (400m x 400m) domains selected to perform simulations of the LIAISE IOPs (July 2021). These domains are also used for the 1st mesoscale models intercomparison (16-18 July 2016). In (c) a zoom over the inner domain and regions considered for the averaging of the fields.

The validation of the model outputs is made through the comparison with the observations from the AWS network of the Meteorological Service of Catalonia (SMC) and satellite-derived fields (such as LST from MSG or MODIS).

It is found that models are able to reproduce the organization of the flow at low levels, where slope winds interact with larger-scale winds (such as the arrival during the afternoon of the sea-breeze generated at the coast, not shown). However, most of the models have some difficulties in reproducing the air temperature and moisture (Figure 2). It is known that during nighttime models are often not able to capture the observed nocturnal cooling and the interactions between the atmospheric and the land surface layers are not well-reproduced. Besides, irrigation is a common practice in the bottom parts of the basin and models do not incorporate this effect resulting in a modelled humidity smaller than the observations.



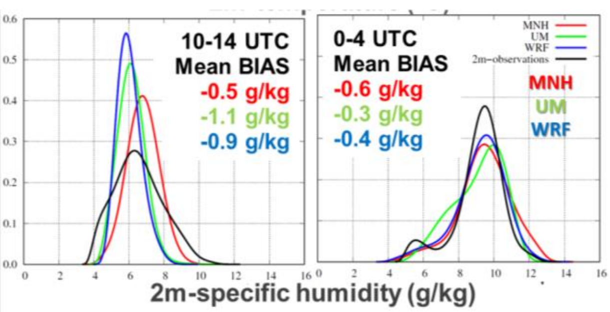


Figure 2. (LEFT) Example of model validation using data from SMC surface network (see location close to a point in Figure 1) and (RIGHT) Probability Density Functions computed over the inner domain of the run for the simulations and observations from the SMC network of AWS.

Due to the complexity of the surface heterogeneities in the LIAISE region, the physical mechanisms that take place in the surface are further explored. It is found that the most frequent surface cover types per pixel (Figure 3) are different in each of the participant models. This fact has an impact on the averaged terms of the surface energy balance (SEB) and other surface features (Figure 4). For each model considered, there are not significant differences in the SEB terms between the regions (irrigated, rainfed) but for a particular region each model has a particular relative importance of each SEB term (in some models H and LE are close and in others LE is nearly zero). Instead, the evolution of the land-surface temperature depends on each region considered.

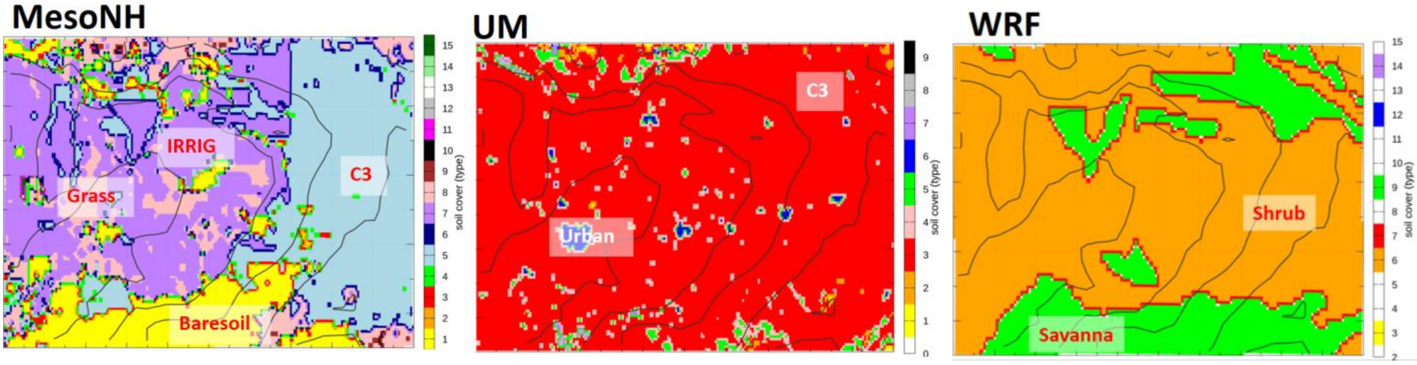
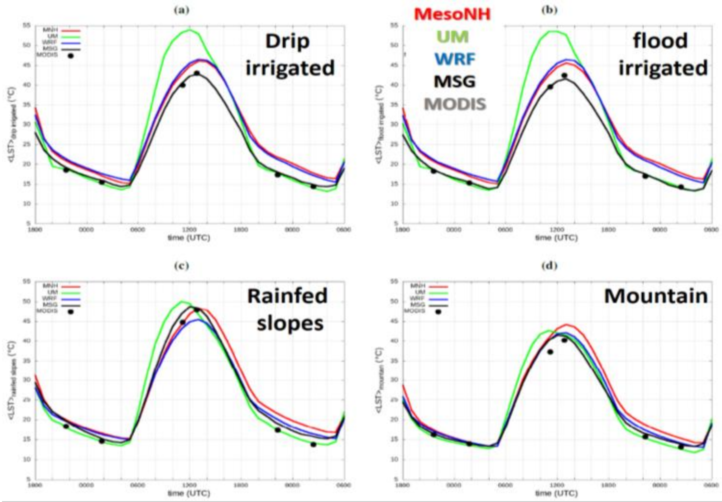


Figure 3. Most frequent soil use per pixel over the bottom parts of the basin.



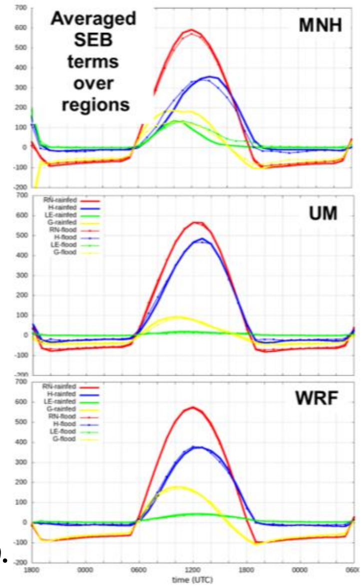


Figure 4. Averaged temporal evolution for the (LEFT) surface temperature and (RIGHT) surface energy balance terms over different regions (Figure 1c).

Results of this 1st incomparison exercise (Jiménez et al., 2024) are useful to identify which model options produce the most realistic organization of the flow at low levels through the comparison between the model results and data from AWS SMC network. Simulations of IOPs during the LIAISE experimental field campaign (July 2021 and the extended period) will be performed during the next special project. Thus, model results will be compared to the high-density observations available during the campaign (soundings, surface energy balance stations in 9 locations, aricraft, lidar, ...) to better evaluate the interaction between the surface and the atmosphere in the models.

Preliminary simulations with the MesoNH model are already done (Lunel et al., 2024). Results show the importance of having a good description of the surface processes (such as the irrigation) to properly capture the initiation and evolution of the *Marinada* (a local wind corresponding to the sea-breeze generated at the coast that propagates inland) in the eastern Ebro River basin.

2. The sea-breeze features in a complex terrain island.

During previous spesturb projects, mesoscale simulations over the island of Mallorca have been made to further understand the organization of the flow at low levels. At the end of the previous special project, the focus of the research was the interaction between locally-generated winds in the Palma basin (west side of the island, see Figure 4). Several simulations of some selected sea-breeze (SB) events were performed, based on the filter proposed by Grau et al. (2021). Most of the SB days take place during the warm months of the year (about 50% of these days) but the filter also selects 1-2 days per year during winter.

Results from the previous special project indicated that the SB in the Palma basin in July is stronger than in January, in agreement with the horizontal thermal gradient between the sea and land. The advection of the cold air from the sea is also more noticeable in summer because when it reaches a certain site in the basin the radiative warming stops. The propagation of the SB front is clearly seen in summer but it is reduced to a coastal circulation in winter. Also, sensitivities in the horizontal resolution showed that resolutions of about 200m are needed to properly reproduce the organization of the flow at low levels in the basin as well as the interactions between the circulations of different scales (slope winds and SB, for instance).

In the current special project, the basin at the northeast side of the island is taken (Alcúdia Basin, Figure 5) because its shape and dimensions is completely different from the Palma basin and this might result in a different organization of the flow at lower levels. The bottom parts of the Alcúdia basin are flat and mainly devoted to agriculture. SB is from northeast, opposite direction to the SB in the Palma basin and the general synoptical winds (westerlies at this latitude). Therefore, we expect that the interactions between the SB with larger/lower scale winds in the Alcúdia basin will be different than in Palma basin.

The density of the surface observations in the flat area and in the mountain slopes of the Alcúdia basin is lower than in other basins (see dots in Figure 5, left). Since January 2021, and thanks to a research project of the Balearic Islands Government, 4 AWS were installed at the foothills of the mountains to measure the interaction between the SB and the slope winds. The simulated cases are selected taking into account that SB is present in the Alcúdia basin (according to Grau and Jiménez, 2024, adapted from Grau et al., 2021) and there are available observations in those 4 sites.

The case of 21 July 2021 is taken as an example of SB with weak large scale winds and the case of 21 August 2021 when the SB was strongly influenced by a southern warm large-scale advection. Finally, a winter SB is also selected (24 February 2021) to evaluate the importance of the horizontal thermal gradient (lower in winter than in summer).

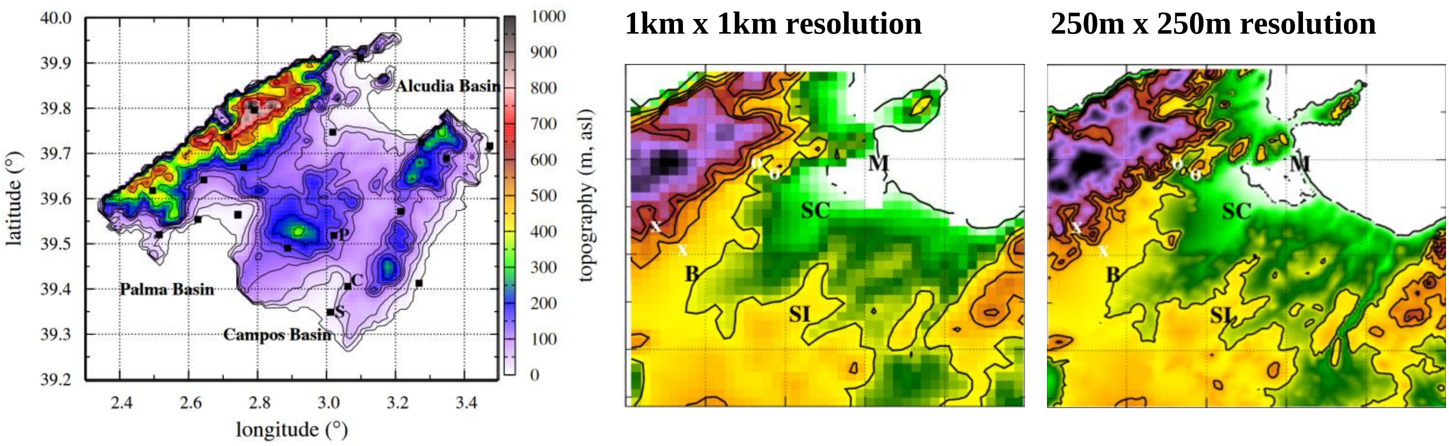


Figure 5. (LEFT) Topography of the island of Mallorca (corresponding to the domain 2 of the simulation). (RIGTH) Comparison of the topography at 1km resolution (domain 2) and at 250m resolution (domain 3).

Three nested domains are taken at different horizontal resolutions (Figure 5): 5km x 5km covering the Balearic Islands, 1km x 1km over the island of Mallorca and 250m x 250m centered in the Alcúdia basin. The vertical resolution is 3m close to the surface and stretched above. Runs are 36h-long, starting at 1800 UTC of the previous SB day. Initial and lateral boundary conditions are taken from the analysis of the ECMWF model.

A summary of the results is shown in Figures 6, 7 and 8. It is found that during winter, the SB is concentrated at the coast whereas during summer the SB propagates inland, interacting with the already generated slope winds (Figure 6). When larger scale winds are moderate and with the direction against the propagation of the SB front, the intensity of the wind speed is reduced (case 21 August 2021). However, if larger scale winds are weaker (21 July 2021) the SB is present in the three main basins and the corresponding SB fronts interact close to the center of the island. Numerical results also point out that the sea-breeze front propagates inland as a cold and humid advection (Figure 7).

24 February 2021 **21 July 2021** **21 August 2021**

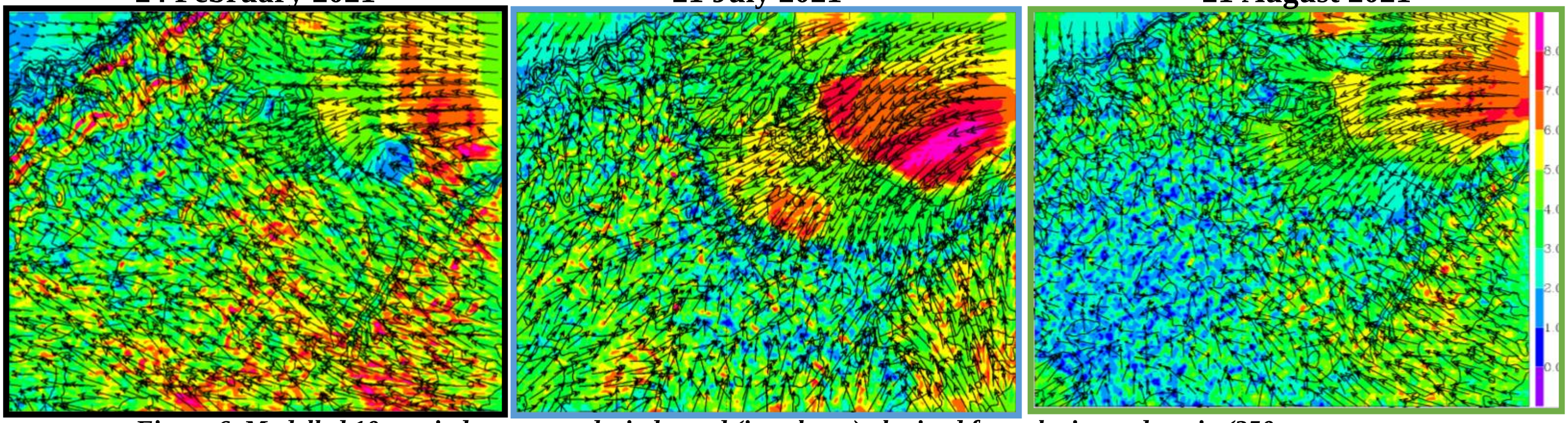


Figure 6. Modelled 10-m wind vectors and wind speed (in colours) obtained from the inner domain (250m resolution) for 3 simulated cases at 1200 UTC.

(a) **(b)**

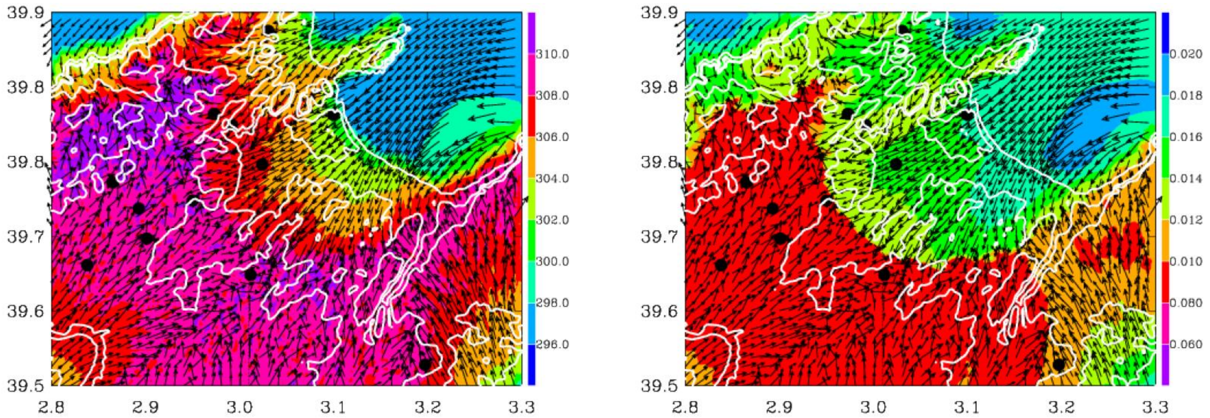


Figure 7. Modelled 10-m wind vectors at 1300 UTC for the 21st July 2021 together with (a) 2m-potential temperature and (b) 2m-specific humidity. White lines indicate the topography.

Regarding the nocturnal circulations (Figure 8), results show that a land-breeze circulation is generated in summer and in winter but it is stronger for the case when large-scale winds are weak in summer. However, all cases show that downslope winds are present at the mountains that close the basin, enhancing the land-breeze flow.

25 February 2021 **22 July 2021** **22 August 2021**

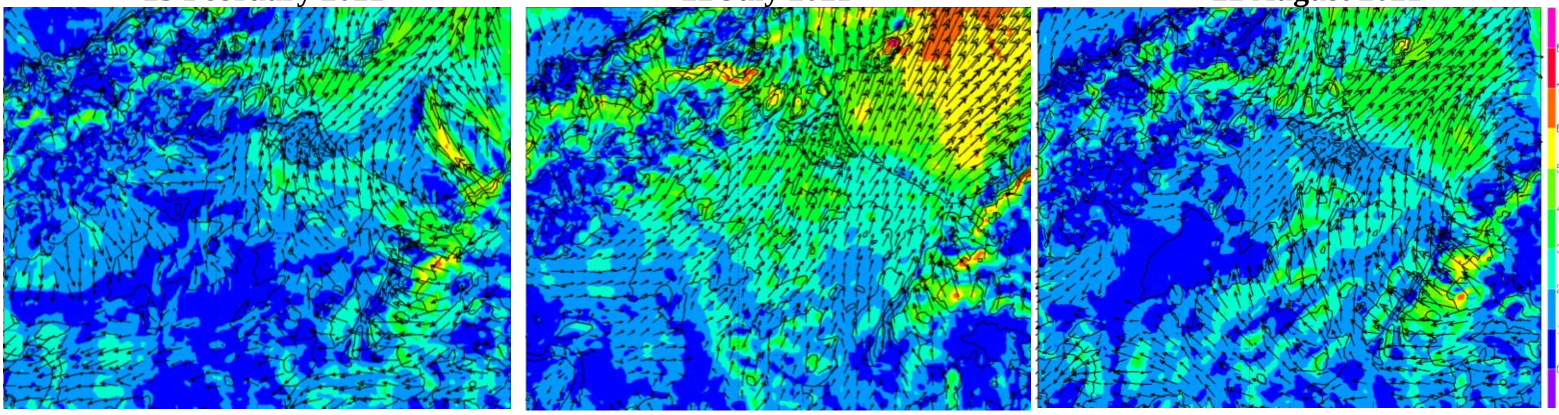


Figure 8. The same as Figure 6 but at 0000 UTC.

Inspecting the organization of the flow of the 1km-resolution fields (domain 2 of the run, not shown), these circulations are still found although they are smoother than for the domain 3 (Figures 6, 7 and 8), pointing to the need of using resolutions of about 200m (or even more) to properly characterize the interactions between the coastal breeze and the slope winds.

Results also show that the simulations are useful to study the interaction between the SB front and the locally-generated slopes. As an example, the time series of the vertical profiles at two locations in the Alcúdia basin are shown in Figure 9. Sa Canova is placed in the lowest part of the Alcúdia basin (labelled as SC in Figure 5). There SB reaches the area at about 1100 UTC and it is maximum at about 1800 UTC (see Figure 9.left). Instead, Son Garreta is placed at the foothills of the northern mountain range at the exit of a valley (see location in Figure 5 labelled with a “o”). After sunset, upslope winds are found in Son Garreta (winds from 135º between 0600 and 0900 UTC, Figure 9.middle) but this is not captured by the domain 2 (at 1km resolution, Figure 9.right). Afterwards, close to 1200 UTC the intensity increases due to the arrival of the SB front. Close to 1400-1500 UTC, the easterly wind corresponds to the arrival of the SB front from the Pollença Bay (at the north of the island) but afterwards the wind direction is again from the southern sector, corresponding to the SB front of the breeze generated in the Alcúdia basin.

A methodology is under development to validate the runs with the available observations (see symbols in Figure 5). Preliminary results are shown un Table 1. It is found that model still have difficulties in reproducing the observations at the foothills since higher spatial resolution would be needed. However, results are satisfactory for the bottom parts of the basin, allowing us to further explore the propagation of the SB front through the basin using these mesoscale simulations.

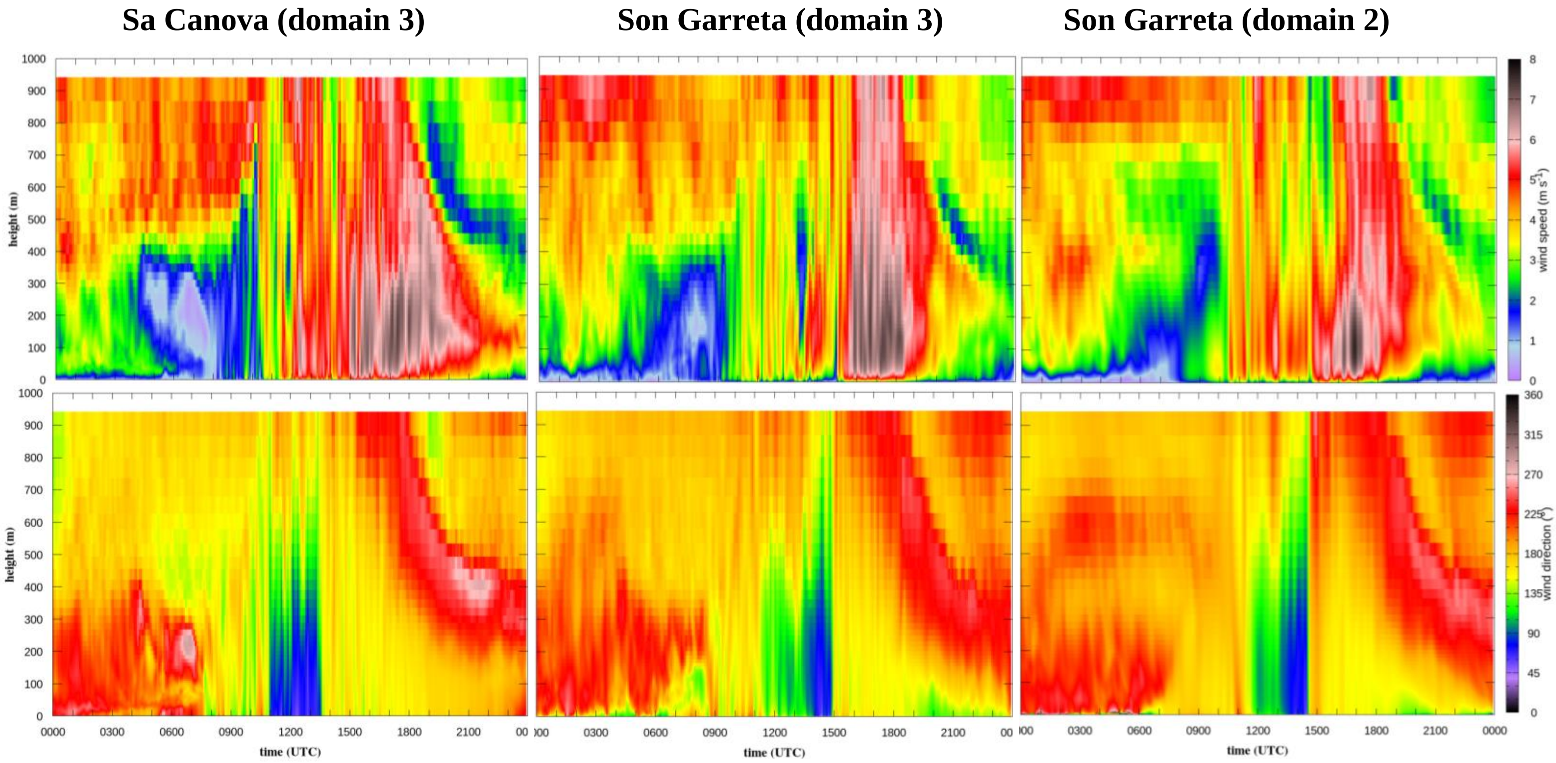


Figure 9. 24-h evolution of the vertical profiles (every 5min) obtained from the inner domain of the simulation (250m resolution, case 21 August 2021) at different sites: Sa Canova (labelled as SC in Figure 4) and Son Garreta (labelled as o in Figure 4). For the latter, the profiles obtained from the domain 2 (1km resolution) are also included.

	T [°C]		q [g/kg]		wind speed (m/s)		wind direction (º)	
ALL	0.5	-0.4	-1.1	-0.5	1.1	0.5	1	1
day	0.0	-0.3	-2.6	-1.8	1.7	0.8	-13	9
night	1.9	0.9	-0.3	0.4	0.3	0.6	-103	-11

Table 1. Mean biases computed from the AWS from the Spanish meterological service (AEMET, in blue) and those computed from the observations made at the foothills of the mountain (in black) for the 2m temperature and humidity and the 10m-wind. Mean values are also computed taking into account the whole simulated period and during day (1200-1500 UTC) and night (0000-0300 UTC).

To further characterise the propagation of the sea-breeze front inland, a parameter is calculated to show the different sea-breeze phases that occur during the diurnal cycle. From the hourly simulated fields, the points of the bottom parts of the Alcúdia basin (see Figure 10.left) are classified according to the 10m-wind direction. A time series of the percentages of points where the wind is from North, East, South and West are shown in Figure 10.right. It is found that the wind direction is mainly from South and West during nighttime whereas during the day it has an opposite direction, corresponding to the land and sea-breezes respectively. Before/After sunset/sunrise this parameter also shows the transition between both regimes. In the mature phase of the sea-breeze (1200-1600 UTC), winds are mainly from North and East but for about 40% of the points winds are from South and West. They are related to the upslope winds generated at the slopes of the northern and southern mountain ranges that close the basin. Regarding the wind intensity (Figure 10.right) this parameter captures the maximum wind speed for the points under sea breeze conditions and upslope wind circulations as well as their diurnal cycles.

This parameter will be calculated for the simulations that will be carried out in the framework of the new special project to further compare the diurnal cycle of the sea-breeze for different basins or larger-scale forcings.

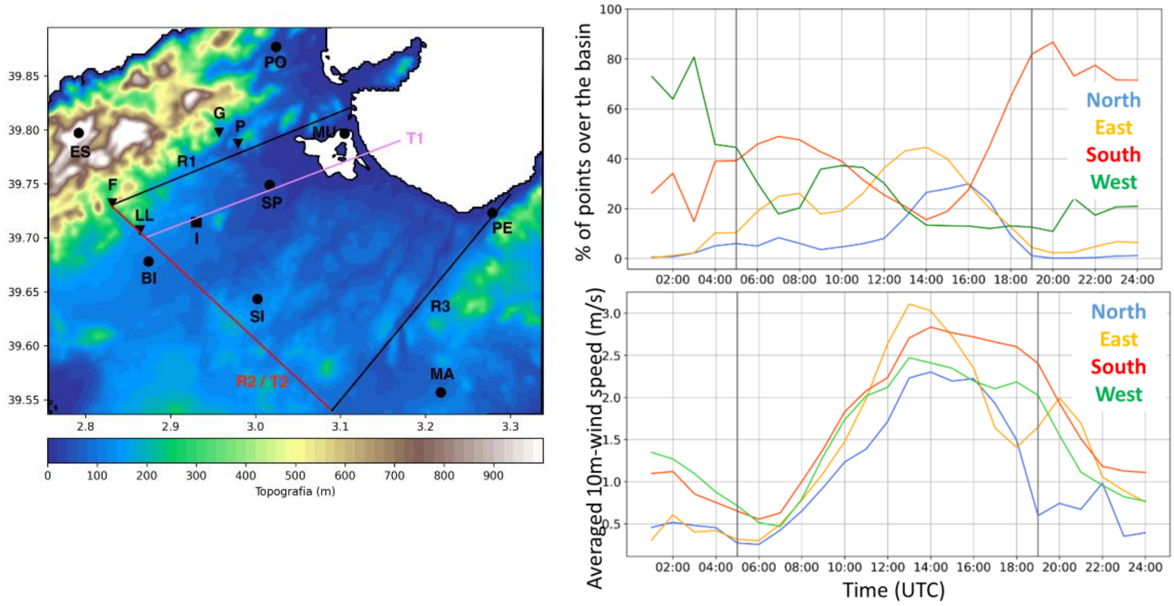


Figure 10. (Left) Topography of the Alcúdia basin with the square that indicates the bottom parts of the basin. (Right) Time series of the evolution of the points for each wind sector and the corresponding averaged temperature.

List of publications/reports from the project with complete references

T.R. Lunel, M.A. Jimenez, J. Cuxart, D. Martinez-Villagrasa, A.A. Boone, P. Le Moigne (**2024**) The Marinada Fall Wind in the Eastern Ebro Sub-basin: Physical Mechanisms and Role of the Sea, Orography and Irrigation, *Accepted in Atmospheric Chemistry and Physics* https://doi.org/10.5194/egusphere-2024-495

M.A. Jiménez, J. Cuxart, A. Boone, P. Le Moigne, T. Lunel, J.R. Miro, J. More, J. K. Brooke, M. J. Best (**2024**) Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE): 1st modelling intercomparison, *submitted to QJRMS journal*.

A. Grau and M.A. Jiménez (**2024**) The importance of the surface features in the initiation and propagation of the sea-breeze front, *in preparation to submit to a journal*.

M.A. Jiménez (**2023**) Numerical and observations studies of the sea-breeze in the Mallorca island 12th MesoNH user's meeting, Toulouse (France) http://mesonh.aero.obs-mip.fr/mesonh57/TwelfthUsersMeeting?action=AttachFile&do=get&target=20231018_1430_jimenez.pdf

L. Marí (**2023**) A numerical study of the sea-breeze in the Alcudia basin (Mallorca), bachelor thesis, Physics Degree at the University of Balearic Islands http://hdl.handle.net/11201/162682

A. Grau, M.A. Jiménez and J. Cuxart (**2021**) Statistical characterization of the sea-breeze physical mechanisms through in-situ and satellite observations. *Int J Climatol*. 2021; 41: 17– 30. https://doi.org/10.1002/joc.6606

A. Grau, M.A. Jiménez, D. Martínez-Villagrasa and J. Cuxart (**2021**) Observed mesoscale patterns in the irrigated Eastern Ebro basin, *EGU General Assembly* 19 – 30 April 2021 (virtual).

A. Torres, A. Grau, M.A. Jiménez and J. Cuxart (**2021**) Surface thermal heterogeneities in the eastern Ebro basin and their impact on regional circulations, *8th International Conference on Meteorology and Climatology of the Mediterranean (MetMed)* 25 – 27 May 2021 (virtual).

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The continuation of this special project is the current one entitled "Physical mechanism at a basin scale in complex terrain regions: persistent fog and sea-breeze front propagation" (2024-2026). The research activity will continue to focus on the Eastern Ebro River basin and the Island of Mallorca because the researchers involved in the special project have organized experimental field campaigns in both regions to further validate the model outputs. The combined inspection of model outputs and observations will be crucial to understand the physical mechanisms involved during sea-breeze and fog conditions, which are very common. To further improve the numerical results, it is planned to increase the horizontal resolution to better describe the surface heterogeneities of both sites. And for the Eastern Ebro River basin irrigation will be activated since it conditions, for instance, the propagation of the sea-breeze (*Marinada*) inland as it is shown in Lunel et al. (2024).