SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2025
Project Title:	PHYSICAL MECHANISM AT A BASIN SCALE IN COMPLEX TERRAIN REGIONS: PERSISTENT FOG AND SEA-BREEZE FRONT PROPAGATION
Computer Project Account:	spesturb
Principal Investigator(s):	Maria Antonia Jiménez Cortés
Affiliation:	Universitat de les Illes Balears (Spain)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	-
Start date of the project:	1st January 2024
Expected end date:	31st December 2026

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	5,000,000	5,000,000	5,000,000	2,115,789
Data storage capacity	(Gbytes)	500	500	500	500

Summary of project objectives (10 lines max)

Two complex terrain regions are taken in this project following the results of the previous one. For the eastern Ebro subbasin, a combined study of in-situ observations and simulations will be carried out to better understand the physical mechanisms that take place during fog events (which are very frequent and can persist for several days), colder pooling within the basin and the propagation of the sea-breeze front (local wind known as *Marinada*). The runs will be based on observations started after the LIAISE campaign and still made at the site. For the island of Mallorca, simulations will be carried out to further understand the interactions between the sea/land breezes with the locally-generated winds of smaller scale and with the winds of larger scale (interactions between the sea/land breezes generated in the three main basins). The studied cases will be based on observations during the AGROWIND experimental field campaign (2021-24), organized by the members of the special project.

Summary of problems encountered (10 lines max)

None

Summary of plans for the continuation of the project (10 lines max)

Following the objectives of the special project, simulations over the island of Mallorca have started. These consist of a sea breeze period lasting 5 days under the influence of high-pressure systems, which allows this regime to develop. However, the characteristics of the sea breeze differ each day (especially during the initiation, maturation and decay phases). In autumn 2025, we will begin simulating the long-lasting fog events observed in the eastern Ebro subbasin in December 2021. The case has already been selected based on data analysis from participants in the experimental field campaign.

List of publications/reports from the project with complete references

M. A. Jiménez, A. Grau, L. Cuadros-Vidal, D. Martínez-Villagrasa, J. Cuxart (**2025**) Characterisation of clear stable nights in summer and lasting fog in winter in the eastern Ebro basin, 10th International Conference on Meteorology and Climatology of the Mediterranean (Toulouse)

M.A. Jiménez, A. Grau, L. Marí, Ll. Cuadros, A. Serra, A. Maimó-Far (**2024**) Study of the physical mechanisms during sea breeze events in the Mallorca island through observations and simulations, European Meteorological Society meeting (Barcelona), EMS2024-838 (oral presentation)

Ll. Cuadros (**2024**) A numerical study to characterize the winter-time sea-breeze in the Alcúdia basin (Mallorca), Final degree thesis (supervised by M.A. Jiménez), Physics Degree at the University of Balearic Islands

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

During previous spesturb projects, mesoscale simulations were carried out over the island of Mallorca to improve our understanding of the organisation of the flow at low levels. Several simulations of some selected sea-breeze (SB) events in the Palma, Alcúdia and Campos basins were performed, using the filter proposed by Grau et al. (2021) to select these events. This statistical analysis, based on observations from the AEMET surface network, shows that most of the SB days occur during the warm months of the year (approximately 50%), although the filter also selects 1-2 SB days per year in winter.

The results for the Palma basin show that the SB is stronger in summer than in winter, in line with the horizontal thermal gradient between the sea and land. Advection of cold air from the sea is also more pronounced in summer, as radiative warming stops once the air reaches a certain point in the basin. The propagation of the sea breeze front is clearly visible in summer, but is reduced to a coastal circulation in winter. Sensitivity tests on horizontal resolution also showed that a resolution of around 200 m is required to accurately reproduce the organisation of the flow at low levels in the basin, as well as the interactions between circulations of different scales (e.g. slope winds and sea breezes).

The organisation of the flow at lower levels during the summer SB in the Alcúdia basin (in the northeast of the island) is completely different from that in the Palma basin. The lower parts of the Alcúdia basin are flat and used primarily for agriculture, whereas the lower parts of the Palma basin are smaller and occupied by the airport and the city of Palma. Simulations of a summer SB event in the Alcúdia basin (Marí, 2023) showed that this wind is from northeast, opposite to the general synoptic winds (westerlies at this latitude) and to the SB already generated in the Palma basin. Therefore, interactions between the SB and winds on larger and smaller scales in the Alcúdia basin are important.

1. Organization of the flow under sea breeze conditions in winter in the Alcudia basin

At the beginning of the current special project the attention focusses on the further exploring of the SB in the Alcúdia basin. A winter SB case is taken (based on observations from the AGROWIND experimental field campaign). The simulation starts at 1800 UTC on 24th January 2022 and ends at 0000 UTC on 26th January 2022. The SB event takes place on the 25th January, when the spin-up of the simulation is completed (more details in Cuadros, 2024).

Three nested domains are considered (see Figure 1), but the results are only analysed for the innermost domain, which has a horizontal resolution of 250 m. For the vertical domain, the resolution is 3 m, stretched to better include the physical processes that occur at lower levels. The simulation strategy is similar to that used in the previous special project: the initial conditions are taken from the ECMWF analysis, and the main parameterisations are turbulence, advection and surface.

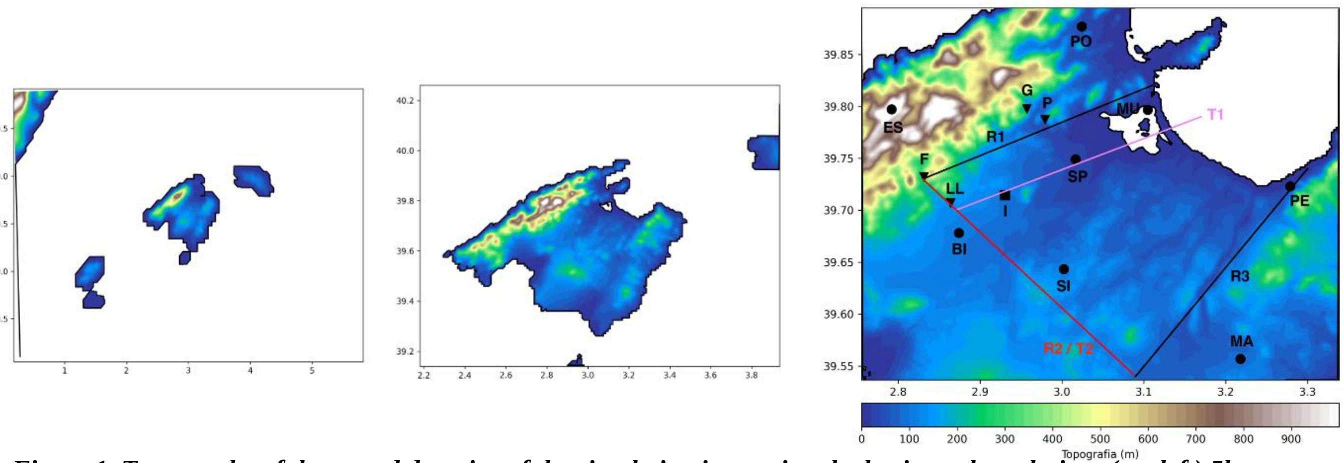

Figure 1. Topography of the nested domains of the simulation increasing the horizontal resolution: (top.left) 5km x 5km; (bottom.left) 1km x 1km; (right) 250m x 250m. In the latter, the locations of the surface observation network are indicated by a symbol and a label. The dots and squares indicate the AEMET stations, while the triangles represent the observations made during the AGROWIND experimental field campaign by the members of the special project.

The results obtained have been validated using observations from AEMET's surface weather stations and data from the AGROWIND experimental field campaign. The model can reproduce the diurnal cycle of the SB (see, for example, Figure 2, which shows a site close to the coast). While the diurnal cycle of temperature and specific humidity is captured well, the model fails to reproduce temperature and humidity during the night. This could be due to the poor spatial resolution needed to reproduce surface heterogeneities, or because the turbulence scheme reaches its limits when winds are weak and nocturnal cooling is strong (i.e. weak and intermittent turbulence). The same run was performed with 3D turbulence, starting at 1200 UTC to represent the night-time cooling of the previous SB day. The results do not change significantly (see the thin line in Figure 2), which suggests that there are difficulties with the model parameterisations in properly reproducing the organisation of the flow at lower levels.

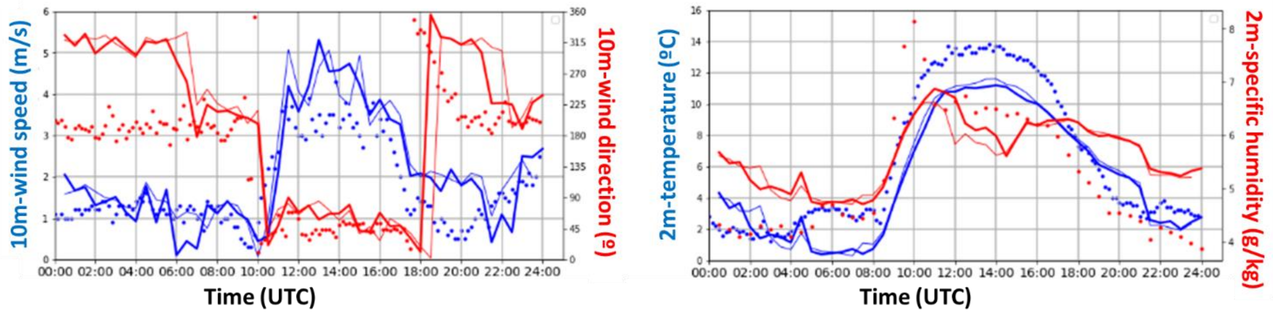

Figure 2. Temporal evolution of 10m wind speed and direction and 2m temperature and humidity for a site near the coast (SP in Figure 1.right). Observations are shown as points and simulations as lines. The thinner line shows the model output using the 3-D turbulence scheme and initiated at 1200 UTC of the previous day.

Inspecting the horizontal cross-sections (Figure 3) at various times reveals that the winds are from the western sector and weak at night (corresponding to the land breeze at 0700 UTC, see Figure 3, left). A maximum wind speed is observed over the sea in the middle of the bay, while the wind is weaker over the land. At 1000 UTC, the land breeze weakens and reverses direction compared to the larger-scale wind over the sea (Figure 3, middle). One hour later, at 1100 UTC, the wind veers and the SB wind direction is present over land, enhanced by the larger-scale wind from the east (Figure 3, right).

Examining the hourly evolution of the horizontal cross-sections for the 10 m-wind (not shown) reveals that this simulated winter sea breeze (SB) is strongly influenced by the larger-scale wind from the eastern sector. This is important at higher levels, but it weakens at lower levels, which allows the SB to form in the lower parts of the Alcúdia basin. Once formed, the SB is reinforced by this larger-scale wind since they have the same wind direction.

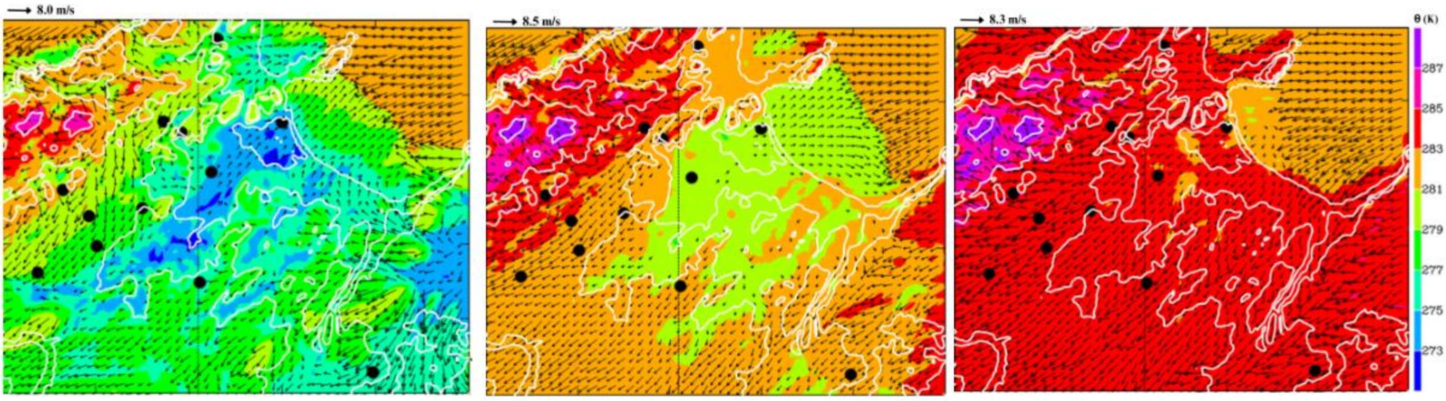

Figure 3. Potential temperature fields at 2m (in colours) together with the 10m wind vectors for the inner domain of the simulation at (left) 0700 UTC, (middle) 1000 UTC and (right) 1100 UTC for the sea breeze event of 25th January 2022.

The results of this winter case were also compared with those of a summer breeze case studied in the previous special project (Figure 4). Preliminary results show that the SB is weaker in winter than in warm months and consequently the temperature and humidity advection are less intense. The results suggest that the horizontal thermal gradient is important for SB occurrence, but other factors, such as the larger scale winds, are crucial for describing the diurnal evolution of the SB.

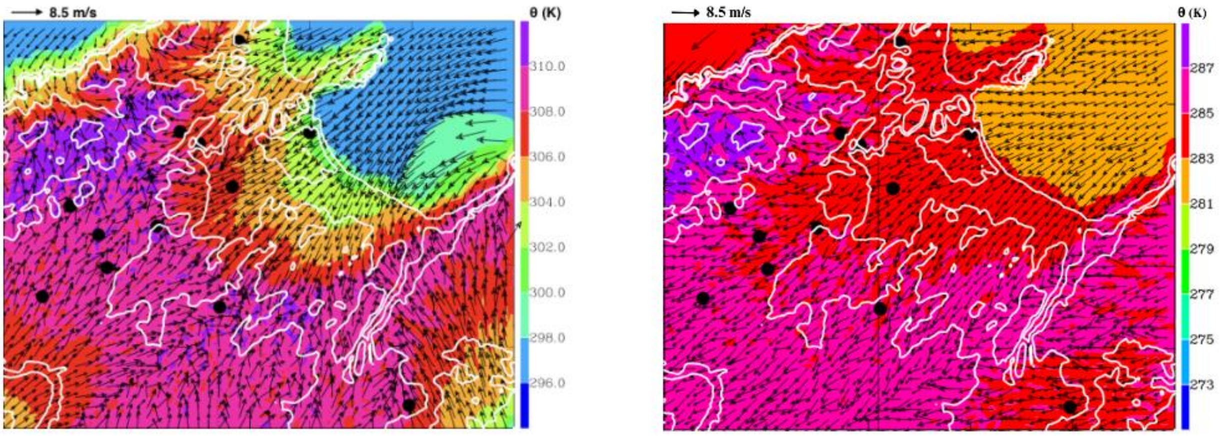

Figure 4. Potential temperature fields at 2m (in colours) together with the 10m wind vectors for the inner domain of the simulation at 1300 UTC for 2 simulated sea breeze events (left) during summe (21st July 2021) and (right) during winter (25th January 2022).

2. Organization of the flow at lower levels during a long-lasting sea breeze event in Alcúdia basin

Attention is now focused on a long-lasting sea breeze event that took place in the Alcudia basin from 12 to 18 July 2022. The simulation strategy is the same as that described above for the winter case. Figure 5 shows the inner domain, together with the vertical cross-section that will be further analysed, and the area at the bottom of the basin where some diagnostics are computed. The simulation is not yet complete, but preliminary results can be found in Figures 6 and 7.

This template is available at:
http://www.ecmwf.int/en/computing/access-computing-facilities/forms

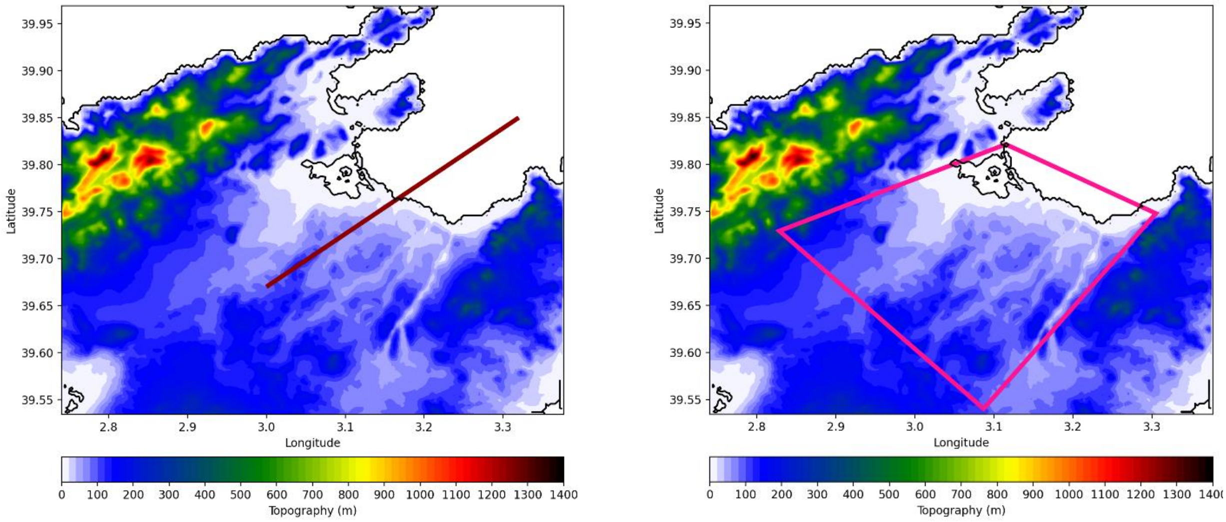

Figure 5. The red line in the left-hand panel indicates the location of the vertical cross-section that will be further inspected. In the right-hand panel, the area at the bottom of the basin shows where some magnitudes are computed to describe the organisation of the flow at lower levels.

The first simulated day is used to demonstrate how the flow is organised at lower levels under sea breeze conditions. During the night, temperatures over land are lower than over the sea, generating a land breeze. Consequently, winds blow from the south-west over the sea in the centre of Alcudia Bay, transporting this cold air from the land to the sea. Locally generated winds (such as downslope winds) also occur over the land, but they are much weaker than the land breeze (Figure 6, left). As the day progresses, solar heating generates a horizontal thermal gradient between the sea and land. The sea breeze front propagates from the coast to inland regions, enhanced by the upslope winds already present. Consequently, the sea breeze is cold and humid due to the maritime origin of the air mass (Figure 6 centre). In the evening, the thermal gradient reduces and the land breeze decreases in intensity, while downslope circulations begin on the mountain slopes that close the basin (Figure 6, right).

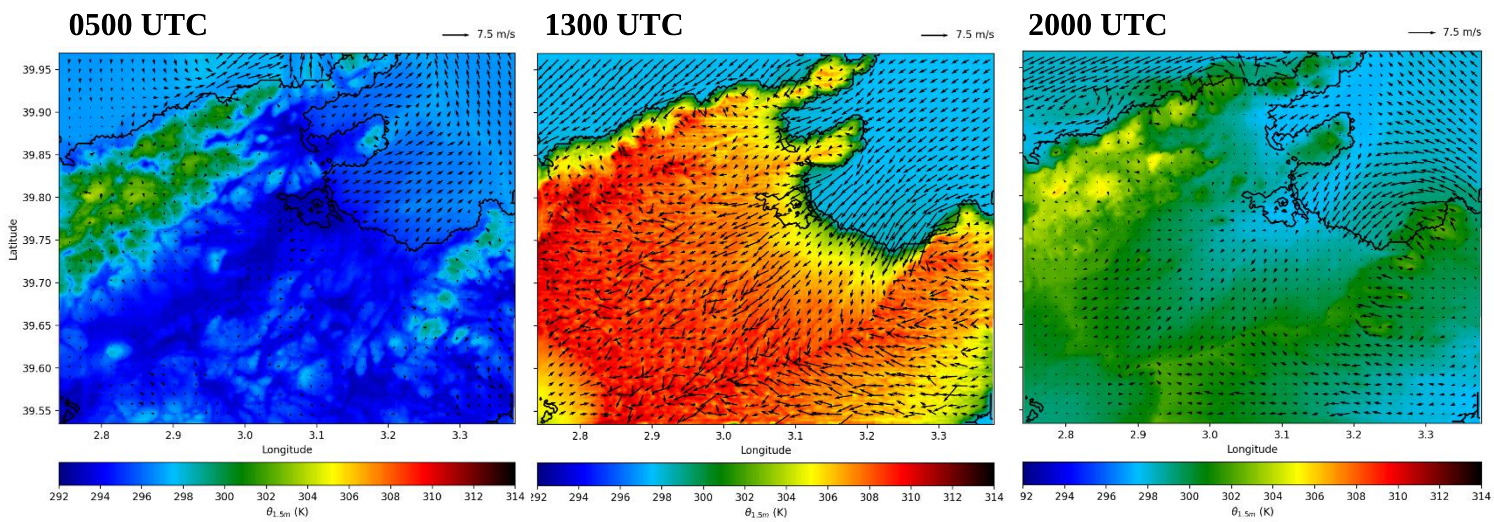

Figure 6. Horizontal cross-sections for the 10m-wind and 1.5m-potential temperature at different instants during the land (0500 UTC), mature (1300 UTC) and decaying (2000 UTC) phases of the sea breeze during 12nd July 2022.

Figure 7 shows that, at the same instants, the vertical cross-sections reveal that the land and sea breezes are responsible for the organisation of the flow at lower levels. The depth is lower for the land breeze than for the sea breeze, which is probably related to the strength of the horizontal gradient that generates the breeze. However, in both cases, the flow is concentrated at lower levels and is not coupled with the organisation of the flow at higher levels.

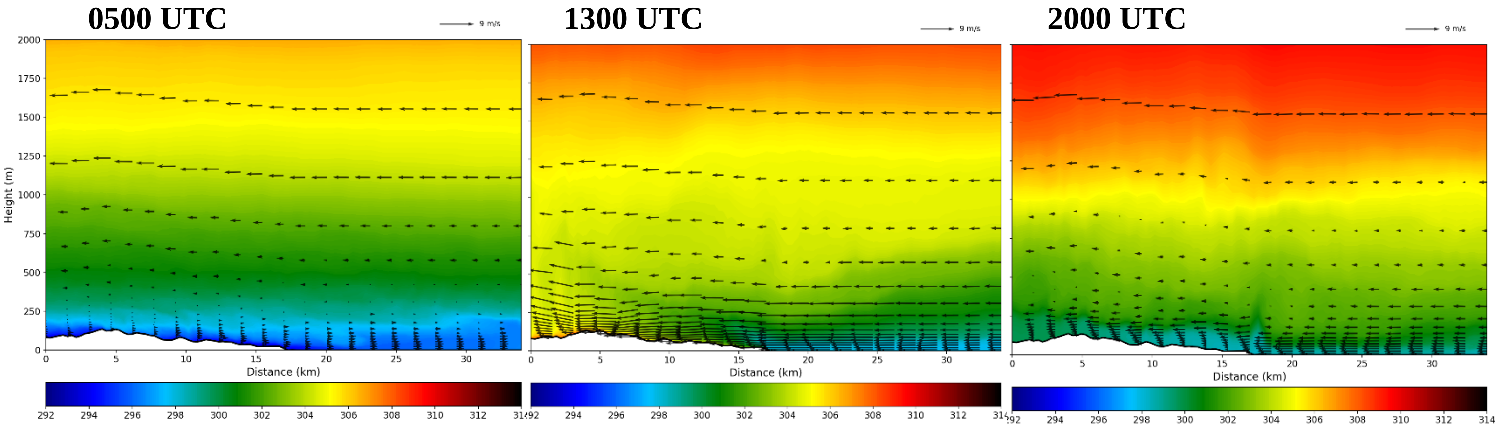

Figure 7. Vertical cross-sections for the wind speed and temperature (in colours) during the land (0500 UTC), mature (1300 UTC) and decaying (2000 UTC) during 12 July 2022.

To compare the spatial and temporal scales of sea breeze conditions during the simulated period, diagnostics are computed for each sea breeze event during the studied week. For example, Figure 8 shows the number of points over the bottom parts of the basin (see Figure 5) for each direction over the first three simulated days. Additionally, the wind speed is averaged across the various wind sectors.

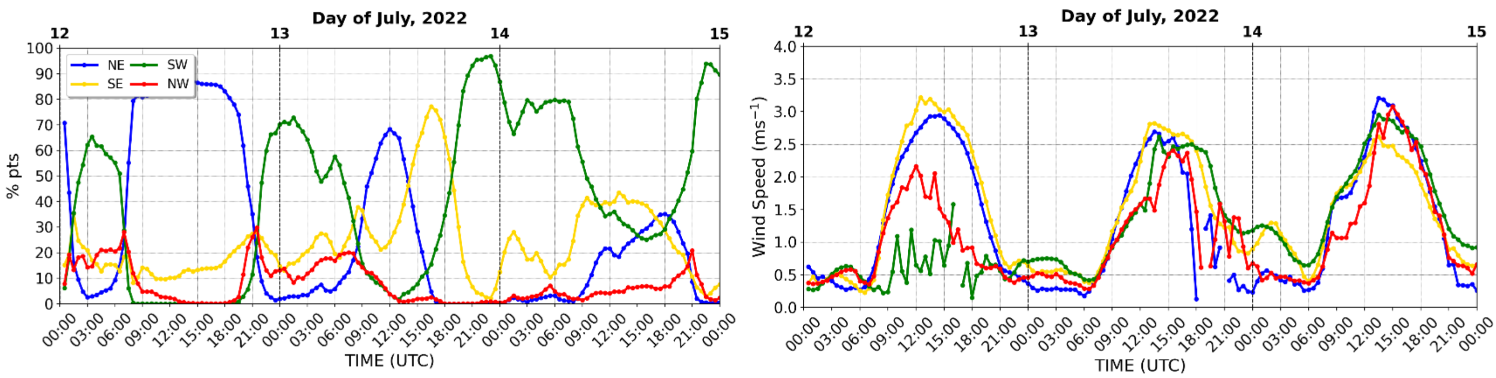

Figure 8. Diagnostics computed to compare the organization of the flow under different sea breeze events in the Alcúdia Basin.

During the day, the sea breeze in this region comes from the NE. Winds from the SW correspond to the sea breeze generated in the Palma basin (the opposite basin), while winds from the NW and SE correspond to circulations generated by the mountain slopes of the northern and eastern mountain ranges. During the night, however, winds from the SW correspond to the land breeze, while those from the other sectors are related to downslope winds.

On the first day (12 July), the sea breeze front generated in Alcúdia Bay reaches more regions, whereas the one from Palma Bay remains confined to the eastern part of the basin. However, the winds are both about 3 m/s. On the second day (13 July), the breeze generated in the Alcúdia basin is less intense due to the arrival of the sea breeze front from the Campos basin (in the south), which is enhanced by a larger-scale wind from the south with similar intensity to the sea breeze. On the third day (14 July), the sea breeze fronts from the Palma and Campos basins propagate faster, probably because they are reinforced by larger-scale winds from the west. Consequently, the formation of the sea breeze in the Alcúdia Bay is delayed, and the sea breeze front propagates inland once the other two (Palma and Campos) decrease in intensity.

This method will be developed to further identify the spatial and temporal scales between sea breeze events, with the aim of improving our understanding of these phenomena.