SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	EFFECT OF SURFACE HETEROGENEITIES AND EVAPOTRANSPIRATION CHANGES ON THE ATMOSPHERIC BOUNDARY LAYER
Computer Project Account:	spesturb
Start Year - End Year :	2018 - 2020
Principal Investigator(s)	Maria A. Jiménez and Joan Cuxart
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Other Researchers (Name/Affiliation):	Antoni Grau (Universitat de les Illes Balears)

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 have participated. Firstly, the plan is to continue performing high-resolution mesoscale simulations of observed cases during the Cerdanya Cold Pool experiments in 2015 and 2017 and the 2018 data in the Aura valley at the northern part of the Pyrenees. These runs are intended to study the cold air pooling and the organization of the flow at lower levels in a complex mountainous terrain region, taking into account the presence of snow. Secondly, the interactions between heterogeneous surfaces and the atmosphere will be explored through simulations based on observational campaigns held in Mallorca dealing with surface heterogeneities (Subpixel in 2016) and in the Eastern Ebro valley in zones with extensive irrigated areas, linked to the LIAISE effort from HyMeX.

Summary of problems encountered (10 lines max)

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 application procedure is clear and the help from the user support service is very useful.

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.)

This project is a continuation of previous SPESTURB special projects. Between 2002 and 2011 the special project was focused on study the stably-stratified atmospheric boundary layer of ideal (Large-Eddy Simulations) and real (mesoscale simulations) cases. Later (2012-2014) the aim of the project was to study the atmospheric boundary layer over topographically complex regions. Afterwards, the previous special project (2015-2017) was more focused in study the atmospheric boundary layer features related to the surface heterogeneities (temperature or soil moisture, among others). During the last 8 years, all the simulations made at the ECMWF are based on observations (experimental field campaigns) or they are made before an experimental field campaign to help in the finding of the locations to perform the measurements. All the runs are made with the MesoNH model (Lac et al., 2018).

The Cerdanya Cold Pool Experiment

The first numerical works of the current special project correspond to some selected IOPs during the Cerdanya Cold Pool experiment2017 (CCP17) that took place in La Cerdanya valley from January to April 2017 (see measurement sites in Figure 1). This valley (about 30km long and 9km wide) is located in the central Pyrenees, oriented along the NE-SW direction. It is a clear example of complex terrain region in terms of topography and soil properties because it is covered by heterogeneous surfaces (forest, grass, rock, heterogeneous distribution of snow, etc). The same area was taken during the previous special project to analyse some selected IOPs during the CCP15 experimental field campaign (October 2015). Now the simulation strategy is similar (2 nested domains at 2km and 400m resolution with a vertical grid of 3 m close to the surface and stretched above), except that during CCP17 snow was present at the mountain peaks but also in the bottom areas of the Valley. In this sense, the snow pack of the model is activated to include the physical processes that take place in snow-covered regions. Besides, the microphysical scheme has been activated (no rain was present in the CCP15 simulations) to allow precipitation (rain and snow) in the simulated domain.

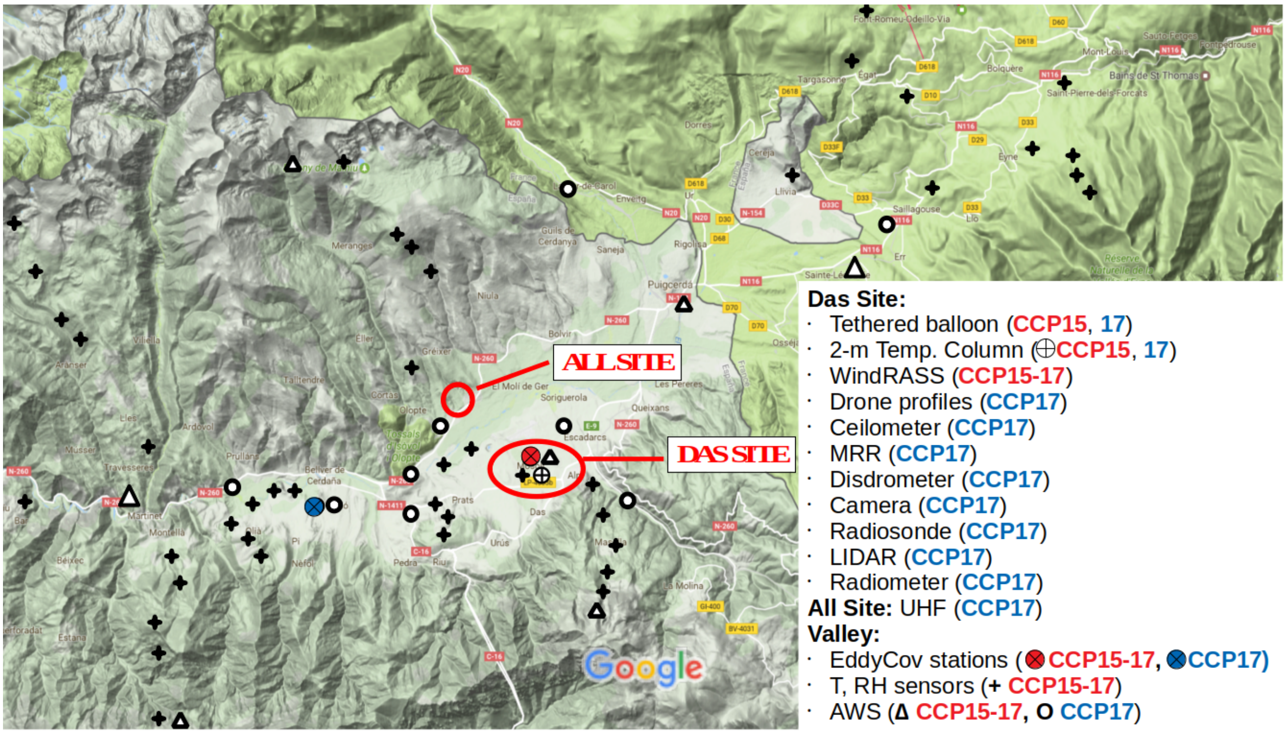

Figure 1. Location of the measurement sites during CCP17. The main site was Das where there are measurements of the surface, the lower layer and the vertical structure of the atmosphere. Besides, different surface weather stations were placed at different sites along the valley (see triangles, circles and crosses).

Three IOPs have been selected to further analyse them through mesoscale modelling:
* **fresh snow covering the whole valley, bottom included** (18 – 19 January 2017),
* **strongly stratified conditions in the bottom of the valleywithout snow** (24 – 30 December 2016),
* **after a snowfall that covered the whole valley, with areas already melted having a heterogenous snow cover** (28 January – 2 February 2017).

These runs are validated with the observations taken during the CCP17 experiment, that included an enhanced surface network of stations, two locations with the surface energy budget and profiles of the lower atmosphere by remote sensing and balloon soundings. The aim of the simulations is to explore the organization of the flow in the valley at lower levels and to evaluate the impact of the presence of the snow in the evolution of the atmospheric boundary layer. In the main site of the campaign (Das, see Figure 1) during clear-sky and weak-wind conditions cold pools are frequently reported (Conangla et al., 2018) and with a combined inspection of the CCP15 and CCP17 simulations and observations it is possible to determine which are the mechanisms involved and the impact of the snow in the cold pool formation or in the organization of the flow at lower levels. Besides, these datasets are useful to validate the model outputs and understand the processes that the model is able to capture, as well as those misrepresented.

All the runs show that the organization of the flow at low levels under clear-sky conditions is strongly influenced by the slope winds (upslope and downslope during day and night, respectively). During night-time mesoscale runs (Figure 2) show that down-valley and downslope winds are present, in agreement with the observations, for any of the simulated surface features: surface heterogeneities (with no snow, Figure 2LEFT) and partially or totally covered by snow (Figure 2MIDDLE and 2RIGHT). Nevertheless, larger scale winds can modify the intensity of the thermally driven winds; especially in the cases when a channelled wind from the Gulf of Lyon reaches the basin from the northeastern sector (see Figure 2, middle).

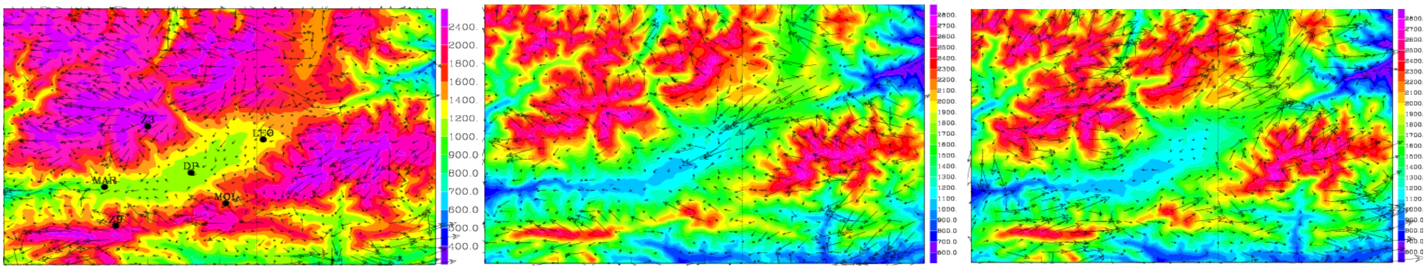

Figure 2. Organization of the flow at low levels (wind vectors at 50 m above the ground) at 0400 UTC for (LEFT) the non-snow case (28 December 2016), (MIDDLE) partially covered by snow (19 January 2017) and (RIGHT) totally covered by snow (31 January 2017).

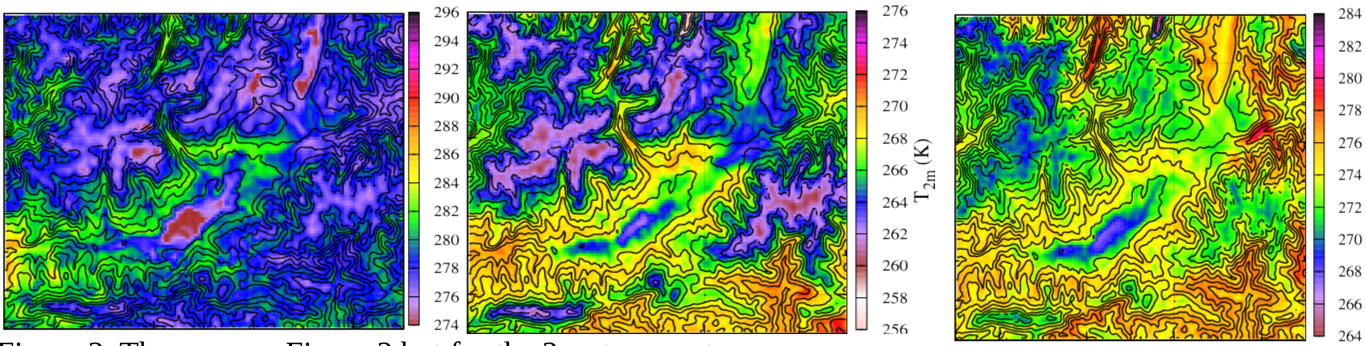

Figure 3. The same as Figure 2 but for the 2 m-temperature.

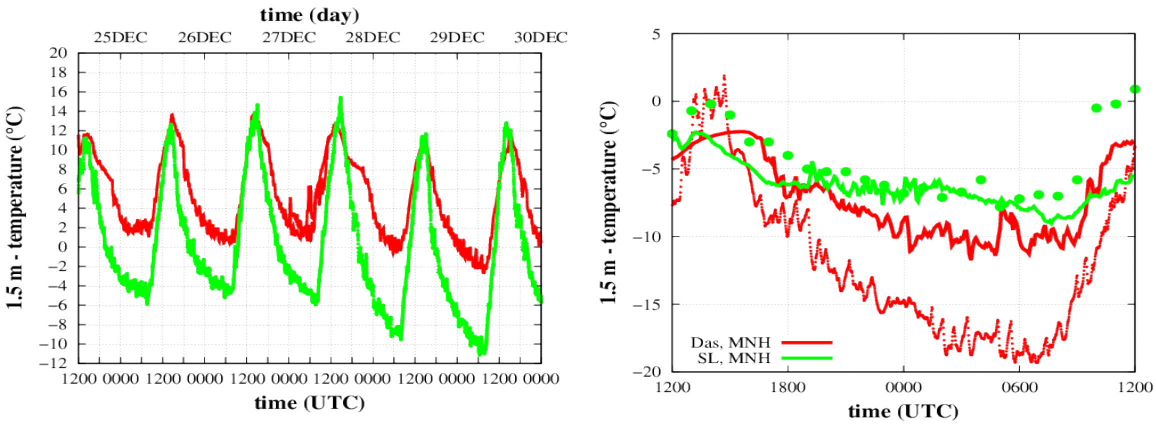

Figure 4. (LEFT) Comparison of the modelled (in red) and observed (in green) temperatures for the strongly-stratified case (24-30 December 2016) in Das. The same in (RIGHT) for the case with the valley covered by snow (18-19 January 2017) for two locations: in the bottom of the valley (Das, in red) and in the upper north-east side (Sainte-Leocadie, in green). Observations are in dots and model results in lines.

Regarding the cold pool features, when no snow is present the cold pool is clearly placed at the bottom part of the basin (Figure 3, LEFT). Instead, the presence of snow tends to homogenise the 2-m temperatures in the bottom parts of the basin (Figure 3, MIDDLE and RIGHT) resulting in a cold pool region less defined and with lesser strength than for the no-snow case.

Figures 4, 5, 6 and 7 show the validation of the model results with some of the observations during the CCP17 experimental field campaign (surface observations, surface energy balance and WindRass).

For the **non-covered snow cases** (Figure 4, LEFT) the model is not able to properly reproduce the strength of the cold pool reported during the case of 24-30 December 2016. It is known that under stably-stratified conditions models have difficulties in reproducing the nocturnal cooling of the air close to the surface, mainly because the surface-atmosphere processes that take place in the lower atmospheric layer are not well captured by models (surface heterogeneities, weak and intermittent turbulence, applicability of MOST, assuming that the imbalance in the surface energy balance equation is zero, among others).

The differences between the modelled and observed 1.5m temperatures might be related to a wrong representation of the processes at the surface (see surface energy balance terms for the non-snow case in Figure 5), among other factors. During day-time, the net radiation is well captured by the model but it overestimates the latent heat (LE) and ground (G) fluxes. It is important to recall that the observed imbalance for this case is large (the same order of magnitude of the net radiation at some time) whereas in the model it is assumed as zero resulting in an unreallistically large G values. During night-time, these terms are generally lower and observations present larger uncertainities than during day-time. As a result, the differences of the modelled and observed terms of the surface energy balance during night-time are large.

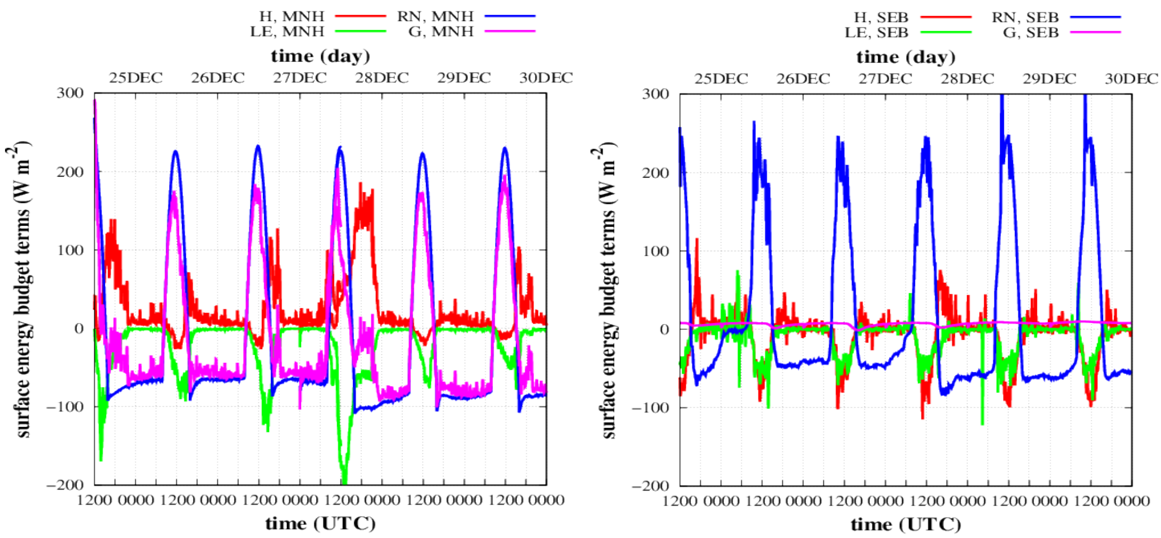

Figure 5. Modelled (LEFT) and observed (RIGHT) surface energy balance (SEB) in Das during the period 24-30 December 2016.

The large values of modelled H are related to a strong shear at lower levels. The inspection of the vertical structure of the atmosphere indicates that the modelled wind at about 100 m above the ground in Das (Figure 6) is overestimated due to the presence of north-easterly winds from the Gulf of Lyon that are channelled in La Cerdanya valley. If the same simulation is done but using Arpege as lateral boundary conditions this mesoscale wind in the Gulf of Lyon is weaker and the channelling effect does not take place.

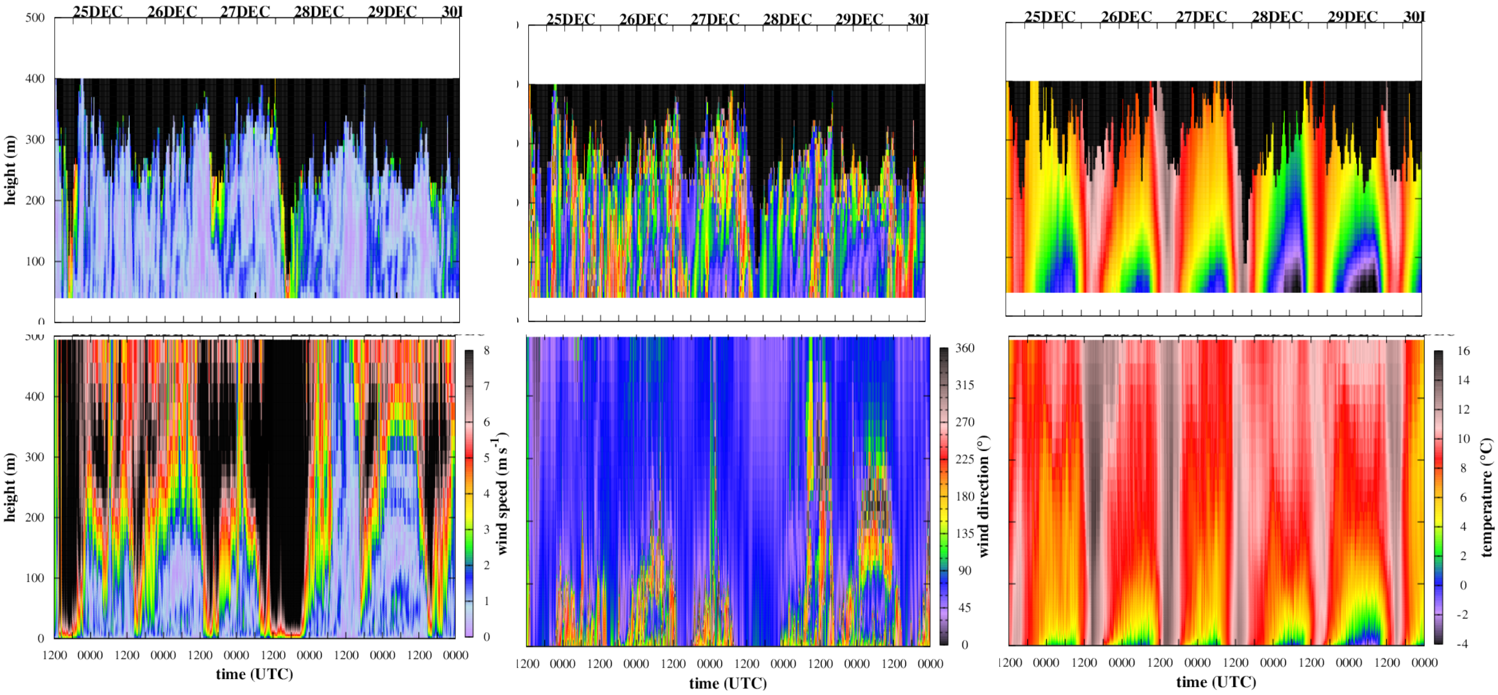

Figure 6. Comparison of the vertical structure observed by the WindRass in Das (TOP) together with the one obtained by the model (BOTTOM) during 24-30 December 2016.

The initial and boundary conditions are better captured for the **snow case** (all the valley covered by snow, 18-19 January 2017, see Figure 4 RIGHT). However, the model still have some difficulties in reproducing the evolution of the temperature at lower levels (inside the cold pool) but it has a realistic behaviour for the temperature above the cold cool (in a surface weather station at the mountain slopes of the north-east side of the valley, in green in Figure 4 RIGHT). The differences between the model and observations for this case are might be related to the representation of the snow in the model. It is important to mention that the presence of the snow is responsible of the low values of the surface energy balance terms that the model tends to overestimate (not shown). Besides, some tests have shown that the modelled snow features (density) or the snow model (physical mechanisms in the snow layer) have an impact on the evolution of the 2 m-temperature but furhter work is need to properly understand the best parameterizations for this region.

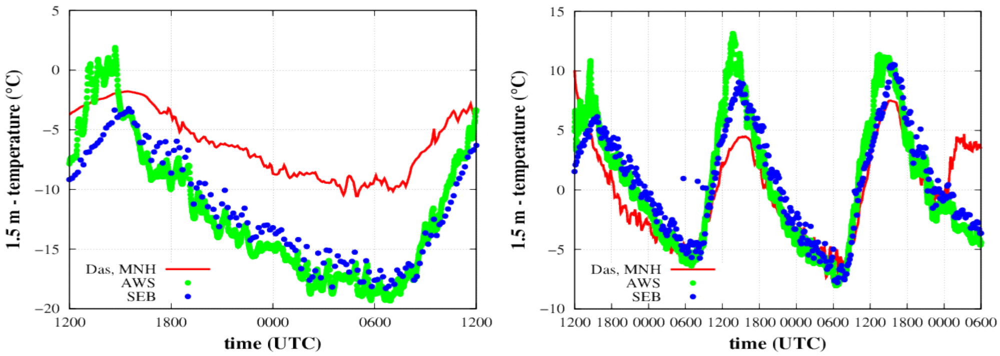

Figure 7. Comparison of the modelled (in red) and observed (in green and blue) temperatures for (LEFT) the snow case (18-19 January 2017) and (RIGHT) the partially covered snow case (30-31 January 2017).

Finally, when **snow partially covers the valley** (30-31 January 2017) the 2 m-temperature is better captured than for the cases of totally covered snow or without snow (Figure 7). This might suggest that the presence of snow tends to homogenise the temperature patterns avoiding a strong radiative cooling of the (flat) surfaces. Besides, when the snow partially covers the valley the differences between modelled and observed ground fluxes are reduced in comparison to other cases (not shown).

We are still working on the analysis of these simulations but results confirm that the surface features (vegetation and partially and totally covered by snow) strongly condition the organization of the flow at low levels and the cold pool features (duration, strength, extension and height). Results have pointed out the difficulties in the model to reproduce the 2 m-temperature evolution in spite of the adequate spatial resolution (400m in the horizontal and 3m in the vertical) suggesting other limitations common in several models such as: representativeness of the surface features in the model, difficulties in reproducing weak and intermittent turbulence, the ranges of applicability of the MOST or a wrong assumption of the zero imbalance in the surface energy balance equation.

Numerical studies of the sea-breeze in the island of Mallorca

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. In the current special project, the focus is in the interaction between locally-generated winds in the Palma basin (west side of the island).

A filter to select sea-breeze (SB) events in the Palma basin using AWS data from 2009-2017 is proposed (Grau et al., 2020). It consists in applying different conditions such as: wind direction from the sea during daytime, a veering of the wind during morning, limiting the wind maxima and no precipitation. 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. To compare the coastal circulations between winter and summer and their interactions with slope winds (from mountains that close the basin) two SB events selected from the proposed filter are studied through mesoscale simulations (the cases of 10 July 2016 and 30 January 2018).

Both runs are 36h long and their horizontal resolution is different to revise the simulation strategy for numerical studies in Mallorca (the vertical resolution is kept the same: 3m at low levels at stretched above). For the winter case, 3 nested domains are taken at different horizontal resolutions: 5km x 5km covering the Balearic Islands, 1km x 1km over the island of Mallorca and 250m x 250m centered in the Palma basin (this third domain is now added in comparison to previous numerical studies in Mallorca). Instead, the summer case is run with 2 nested domains: the outer at 2km x 2km covering the Balearic Islands and the inner at 400m x 400m centered in Mallorca. Figure 8 shows the Palma basin seen by both horizontal resolution runs.

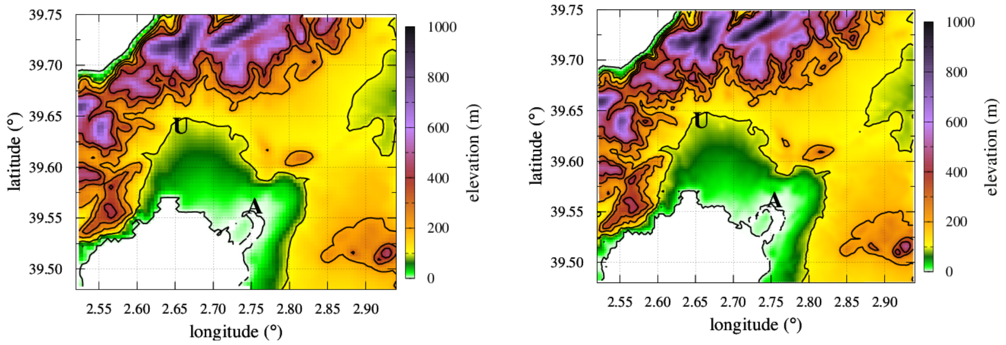

Figure 8. Topography of the Palma basin at (LEFT) 400m x 400m resolution and (RIGHT) 250m x 250m resolution. The locations of the Airport (A) and the University (U) are also indicated.

It is found that the run with 2 nested domains is about 2.2 more expensive (in terms of computational SBU units) than the one with 3 nested domains. From now on, for numerical studies centered in one of the three basins we will use 3 nested domains (the inner one centered in the basin) whereas we will use 2 nested domains (at 2km and 400m) to characterize the organization of the flow at Mallorca scale. This new configuration is more detailed than the one taken from previous studies (at horizontal resolutions for the outer and inner domains of 5km x 5km and 1km x 1km, respectively) and it is updated according to the current computational resources.

Figures 9 and 10 show some model results of the two sea-breeze (SB) events. It is found that the SB in July is stronger than in January, in agreement with the horizontal thermal gradient between the sea and land (Figure 9a). Particularly, for the winter SB case this thermal difference is concentrated to the coastal zones (Figure 9b) whereas for the summer SB case it is much more extensive. The advection of the cold air from the sea is also more noticeable for the summer SB because when it reaches the site (for instance the Airport) the radiative warming stops (Figure 10 top-right).

(a) **(b)**

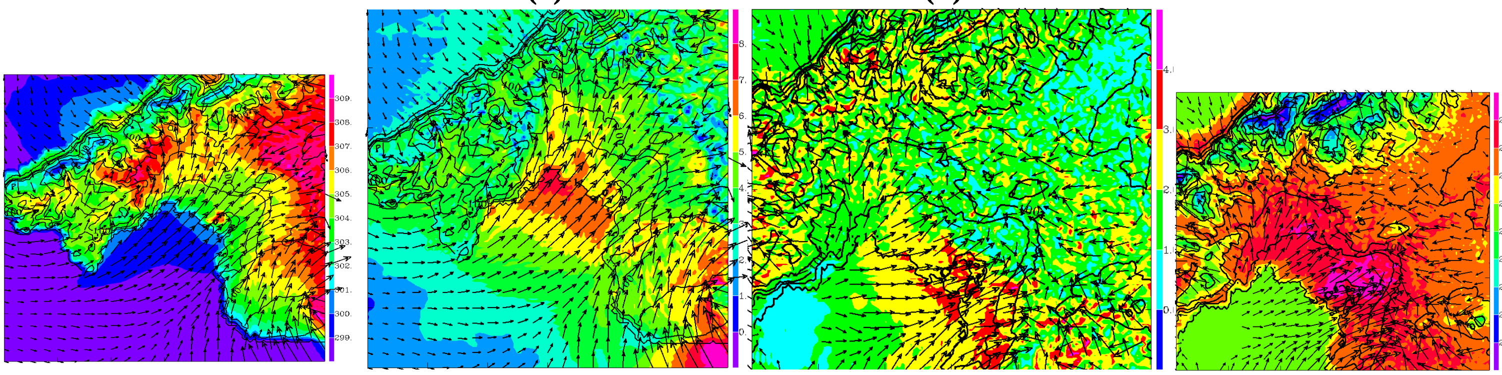

Figure 9. 10m-wind vectors, 2m-temperature and 10m-wind speed (in colours) and elevation (lines) at 1200 UTC for (a) 10 July 2016 and (b) 30 January 2018. Caution that the colours are not the same for (a) and (b).

Airport - wind speed (m/s) **University - wind speed (m/s)** **Airport - temperature (ºC)**

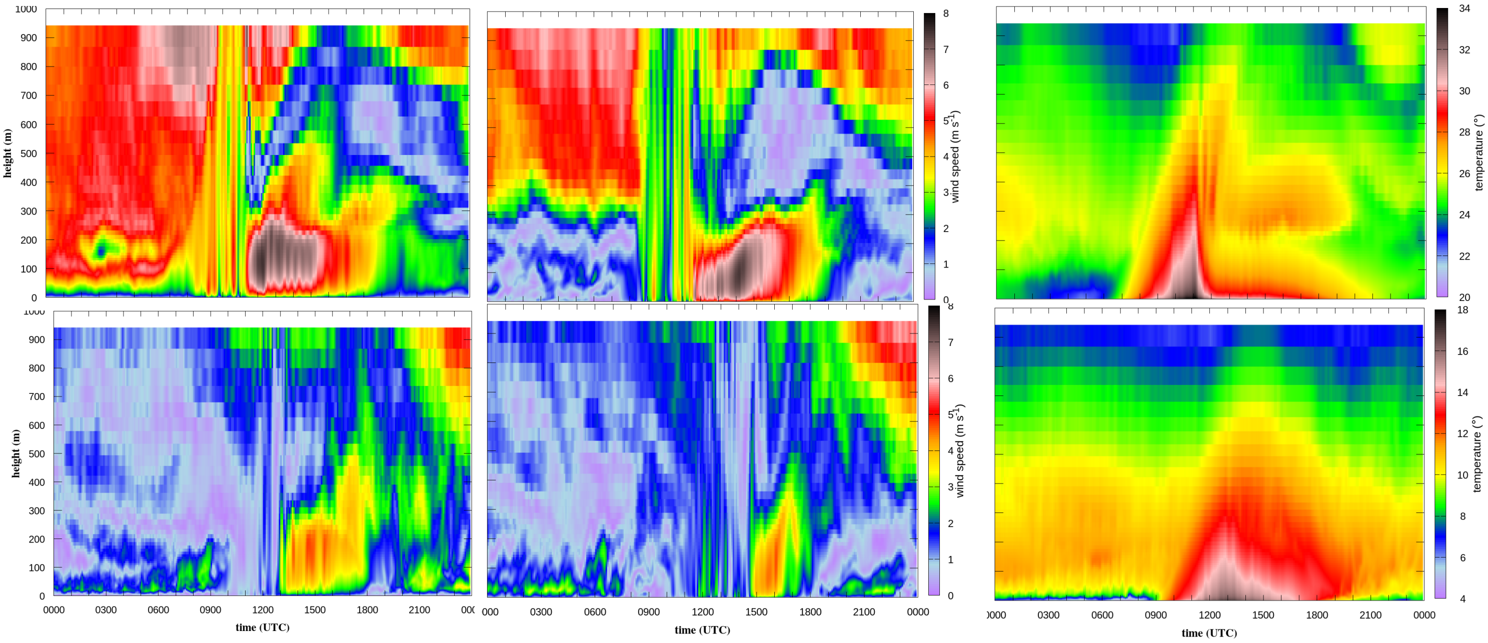

Figure 10. Temporal evolution of the modelled profiles at the Airport and the University (labelled as A and U, respectively, in Figure 8) for (top) 10 July 2016 and (bottom) 30 January 2018.

The propagation of the SB front is clearly seen in summer (it is nearly simultaneous in the coast-Airport and inland-University, Figures 9a and 10top) but it is reduced to a coastal circulation in winter (Figures 9b and 10bottom), where the SB reaches the University (mountain foothills) during afternoon (Figure 10bottom). These preliminary results will be further inspected in the framework of the new spesturb special project to understand the interactions between the SB and the slope winds (and also the SBs generated in the other basins in Mallorca). The main objective is to better characterize the physical mechanisms that take place under SB conditions and if they agree with the results shown in Grau et al. (2020) using surface observations.

List of publications/reports from the project with complete references

M. A. Jiménez, J. Cuxart, A. Grau, A. Boone, S. Donier, P. Le Moigne, J. R. Miró, J. More, A. Tiesi, P. Malguzzi, J. Brooke, and M. Best, **2021**. Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE): 1st modelling intercomparison. *EGU 2021 General Assembly*

M.A. Jiménez, A. Grau, J. Cuxart, **2020**. Generation of Chilling Hours maps using Surface Observatons and Satellite data. Atmospheric Research, 236, 104807 https://doi.org/10.1016/j.atmosres.2019.104807

A. Grau, M.A. Jiménez, J. Cuxart, **2020**. Statistical characterization of sea-breeze physical mechanisms through in situ and satellite observations. Int J Climatol. 2020; 1– 14. https://doi.org/10.1002/joc.6606

M.A. Jiménez, J. Cuxart, A. Paci, L. Conangla, D. Martínez-Villagrasa, and B. Martí, **2020**. Surface thermal inversion evolution in the bottom of a Pyrenean valley studied by observations and mesoscale simulations, *EGU 2020 General Assembly*

A. Paci, M.A. Jiménez, J. Cuxart, M. Lothon, O. Clary, Y. Seity, D. Martínez-Villagrasa, A. Dabas, T. Rieutord, and C. Román-Cascón, **2020**. Exit jet in a narrow Pyrenean valley: the Aure Valley 2018 field experiment, *EGU 2020 General Assembly*

Jiménez, MA, Cuxart, J, Martínez Villagrasa, D. **2019**. Influence of a valley exit jet on the nocturnal atmospheric boundary layer at the foothills of the Pyrenees. *Q J R Meteorol Soc*., 145: 356 375. https://doi.org/10.1002/qj.3437

Conangla; Cuxart; MA Jiménez; Martínez-Villagrasa; Miro; Tabarelli; Zardi. **2018**. Cold-air pool evolution in a wide Pyrenean valley. *International Journal of Climatology*, 38: 2852-2865. https://doi.org/10.1002/joc.5467

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 activities of the current special project are linked to a new one started in 2021 entitled: ***the role of the basin topography and surface heterogeneities in the organization of the flow at low levels***. Now the focus is centered in the eastern Ebro subbasin, a region with irrigated and rainfed regions surrounded by mountains. An experimental field campaign (Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment, **LIAISE**, https://www.hymex.org/?

page=liaise) started in April 2021 and will end by July 2021 (it has been delayed 1 year due to the COVID-19). Some of the IOPs will be studied with a combination of observations (in situ and satellite-derived products) and mesoscale simulations to better characterize the relation between the surface heterogeneities and the organization of the flow at low levels. Besides, with the new special project, the numerical studies related to the **sea-breeze in the island of Mallorca** will continue. Since January 2021, a total of 4 surface stations have been installed in the Palma and Alcudia basins to complement the observations from AEMET network to further understand the interaction between the breeze and the locally-generated circulations (slope winds). Simulations of some selected IOPs will be conducted in the framework of the new special project.