SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	EFFECT OF THE SURFACE HETEROGENEITIES IN THE ATMOSPHERIC BOUNDARY-LAYER
Computer Project Account:	SPESTURB
Principal Investigator(s):	Joan Cuxart and Maria A. Jiménez
Affiliation:	Universitat de les Illes Balears (UIB)
Start date of the project:	1st January 2015
End date of the project:	31st December 2017

Summary of project objectives

(10 lines max)

The special project than ran between 2015 and 2017 was focused over complex terrain regions with special interest in areas displaying surface-heterogeneous of relatively small scale, reflected in the temperature, moisture, rugosity and parameters of the surface and the lowest part of the atmosphere in contact with them. Simulations over areas showing a large diversity of scales in surface heterogeneities were undertaken, studying the full diurnal cycle and the role of the heterogeneities, for two areas of interest, the island of Mallorca (sea and land breeze cycles), and the Pyrenees (slope and valley flows, cold pools). In all cases there were experimental data form campaigns available (MSB13/14 in Mallorca, BLLAST'11 in Lannemezan and CCP'15 and CCP'17 in the Catalan Pyrenees). Simulations at horizontal resolutions of few hundred of meters for real observed cases have allowed to increase the understanding of the processes and identify model shortcomings.

Summary of problems encountered (if any)

(20 lines max)

Experience with the Special Project framework

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

We think that the procedure to apply for a special project at the ECMWF is adequate. The regulations are clearly presented on the web page. In case of any question, the support team is very efficient and their help is very kind.

Summary of results of the current year (This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project).

This project is the continuation of a former one devoted to the study of the stably stratified boundary layer (2002-2011) which gradually evolved into the study of the Atmospheric Boundary Layer (ABL; 2012-2014) over complex terrain in weak general pressure gradients, allowing to inspect the effect of the terrain-induced flows over the ABL characteristics. The analysis of atmospheric motions in complex terrain is made by our group through the combined use of experimental data (very often from campaigns that we organize or where we participate with our own instrumentation) and numerical modelling. The principal source of computing time for the very high-resolution simulations has been the SPESTURB project at ECMWF with the MesoNH model (Lafore et al., 1998).

The complexity of the studied regions has increased over time. Mesoscale runs made via the SPESTURB project have been focused on studying the organization of the flow at lower levels in:
(i) the Duero river basin: Low-Level Jet (using LES, Cuxart and Jiménez, 2007), cold pool formation (Martínez et al., 2010).
(ii) the island of Mallorca: nocturnal flows (Cuxart et al., 2007; Martínez and Cuxart, 2007; Jiménez et al., 2008) and sea-breeze (Cuxart et al., 2014; Jiménez et al., 2016).
(iii) the Ebro river basin: fog formation (Cuxart and Jiménez, 2012), mesoscale simulations and remote sensing (Cuxart et al., 2012), surface energy balance (Cuxart et al., 2015) and cold-pool formation (Conangla et al., 2018).
(iv) the Pyrenees: characterization of the downslope winds (Jiménez and Cuxart, 2014), description of the flow in a narrow valley N-S oriented (Jiménez et al., 2018, under review), the temperature heterogeneities a different spatial scales (Cuxart et al., 2016) or the evaluation of the anisotropy during the afternoon and evening transitions (Lampert et al., 2016).

From the beginning of this project, we have concentrated our efforts in: **(i)** the Sea Breeze (SB) and Land Breeze (LB) in the island of Mallorca, **(ii)** the organization of the flow in La Cerdanya, an E-W oriented valley in the central Pyrenees about 20km long and 2km wide and **(iii)** further exploring the downslope winds during the BLLAST experimental field campaign (works initiated in the former special project). Results are summarized in the following sections.

1) The sea and land breeze in Mallorca (MSB14 experimental field campaign).

During September 2013 the Mallorca Sea Breeze (**MSB13**) experimental field campaign took place in the Campos basin (at the south of the Island of Mallorca, Western Mediterranean, Figure 1). A morning transition case (from land to sea breezes) was sampled with a multicopter and a tethered balloon. A mesoscale simulation was done of this case with a setup similar to Cuxart et al. (2007). 2 nested domains were taken at 5km and 1km horizontal resolutions and 3m in the vertical (gradually stretched). The observed features during the phases in the morning transition (according to Cuxart et al., 2014) are compared to the model outputs and results are further explained in Jiménez et al. (2016). It was found that **the model was able to reproduce the turning of the wind from the land-breeze towards the sea-breeze directions as well as the thermal structure in the lower atmosphere**. However, the model was not able to reproduce the nocturnal cold pool, resulting in an unrealistic evolution of the temperature at lower levels during the previous phase. Nevertheless, at the end of this phase the model results are more realistic as well as the evolution of the following phases (preparatory and development) during the morning transition. This wrong temporal evolution of the model during the previous phase might be related to a **wrong representation of the surface properties**.

A year later (from 26th May to 6th June 2014) the **MSB14** experimental field campaign took place at the same site. Continuous measurements in Ses Covetes (red cross in Figure 1b) were taken from a surface weather station (high-frequency sampling sensors, sonic), a multicopter and a tethered balloon during the 5 IOPs (see description in Figure 2). Due to the strength of the turbulence in the mature phase of the SB, only vertical soundings were sampled during the night-time and the morning and evening transitions (Figure 2). In order to further understand the observations, a high-resolution mesoscale simulation was done with a similar setup used for the MSB13 case. Besides, a third domain was taken, centered in the Campos basin at 250 m resolution (see Figure 1b).

The modelled organization of the flow at lower levels for IOP3 is shown in Figure 3. Results show that during night-time the air flows out of the island due to the **combined effect of the LB and downslope winds** and a similar interaction happens during the day (SB interacts with upslope winds). Although all model domains behave similarly, the organization of the flow is more realistic at 250m resolution where the topography is better reproduced.

To verify the model results they are compared to the multicopter and tethered balloon temperatures sampled in Ses Covetes (Figure 4). It is found that the model is able to reproduce the thermal structure during the morning and evening transitions. However, it fails to reproduce the strong surface cooling during night-time (as previously described in Jiménez et al., 2016 for the MSB13 studied case). The modelled surface temperature gradient between land and sea is similar to the one reported from satellite (MODIS and Meteosat) indicating that the model is **able to capture this temperature difference** (Figures 5 and 6), one of the main process to start and maintain the sea-breeze. Comparing the model outputs to other sites in the Campos basin (Ses Salines, 1km inland and Porreres, 15km inland) it is seen that the model, especially the inner domain (D3, at 250m resolution) is closer to observations (Figure 4).

It is important to mention the limitations to verify the model outputs in coastal and mountain regions. Terrain and soil uses, among others, change drastically and this variability is not included in the surface databases that models typically use. This fact can explain the differences between the model and single-point observations or satellite-derived products.

The mesoscale simulations made in this special project based on the MSB13 and MSB14 experimental field campaigns have shown that the model experiences some difficulties in reproducing the calm wind conditions close to sunrise and sunset, corresponding to the veering of the wind. Besides, it is not able to reproduce the strong nocturnal cooling at night. Instead, the model is able to reproduce the thermal gradient between the land and sea during sea and land breeze conditions, being this forcing well captured when the temperature gradient is compared to the satellite fields. These results are further described in Jiménez et al. (2017). Increasing the horizontal resolution has an impact on the results (closer to observations) but there are still some mechanisms that are not properly captured by the model such as the surface-atmosphere interactions, and besides sometimes an inadequate representation of the soil properties in the data bases of the model. It will be worth in the future to include the heterogeneity of the surface (surface cover, soil moisture, …) with values closer to the reality in the mesoscale simulations.

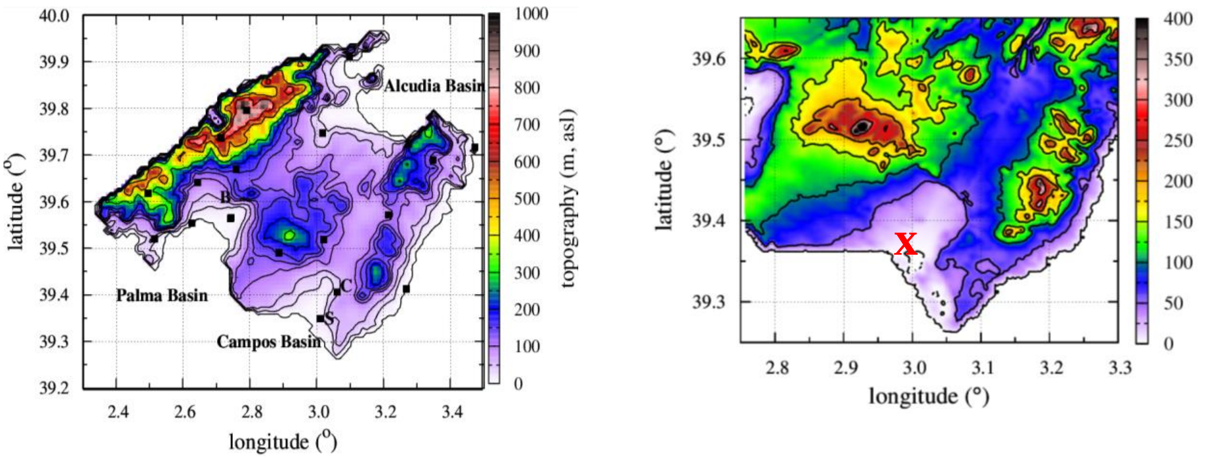
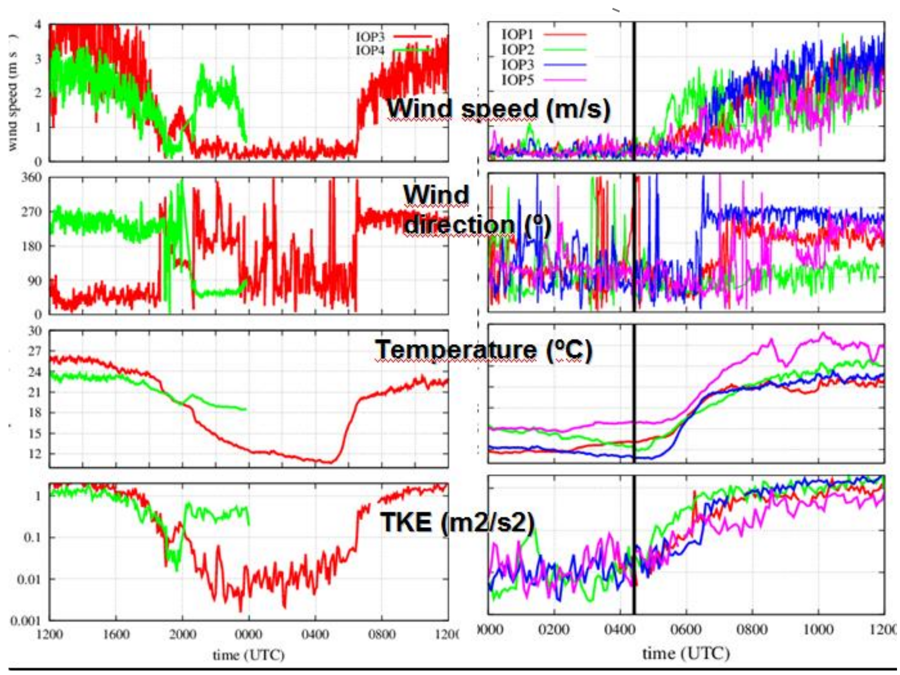


Figure 1. Topography of (LEFT) the second domain (at 1km resolution) of the run and (RIGHT) the third nested domain at 250m resolution. The location of the main site during MSB14 (Ses Covetes) is indicated with a red cross and in dots the surface weather stations from AEMET used to verify the model outputs.



IOP	period
1	30/May 0400 - 0900 UTC morning SB initiation with clouds after the turning
2	31/May 0300 - 0700 UTC nocturnal cooling with a high katabatic. SB initiation with strong wind
3	2/June 1800 UTC - 3/June 0700 UTC nocturnal cooling (katabatic) followed by SB initiation polluted with strong wind
4	4/June 1600 - 2000 UTC evening transition of SB with strong winds at the end that do not allow development of katabatic winds
5	6/June 0300 - 1200 UTC nocturnal cooling (katabatic) followed by SB initiation polluted with strong wind and clouds

Figure 2. Observations in Ses Covetes (red cross in Figure 1) during the 5 IOPs of the MSB14 experiment.

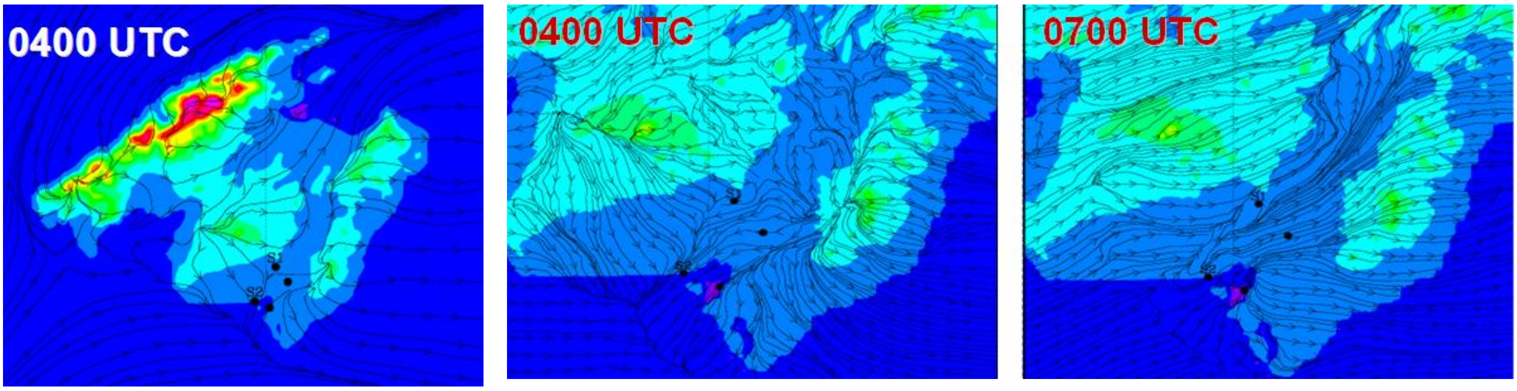
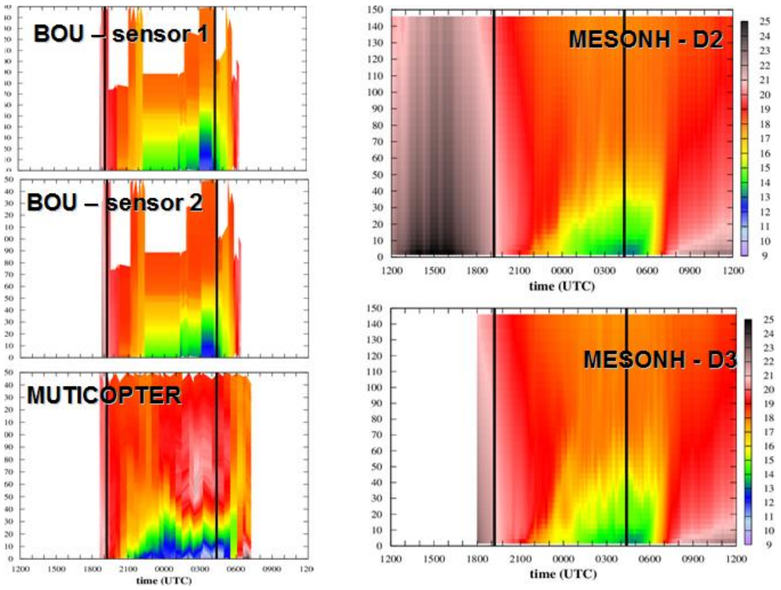


Figure 3. Streamlines at 10m (agl) over the topography (in colours) during IOP 3 (3rd June 2014) at 0400 UTC and at 0700 UTC, for the land and preparatory phases of the diurnal cycle of the SB, respectively.



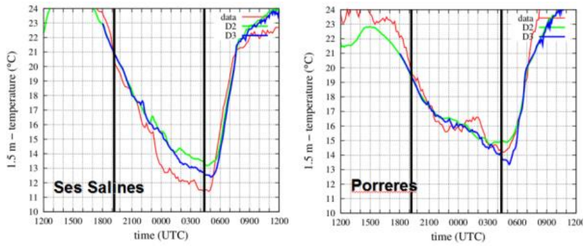


Figure 4.
(LEFT) Observed and simulated time series of the vertical profiles for temperature.
(TOP) Modelled and observed time series of the 2m temperature at two different locations in the Campos basin.

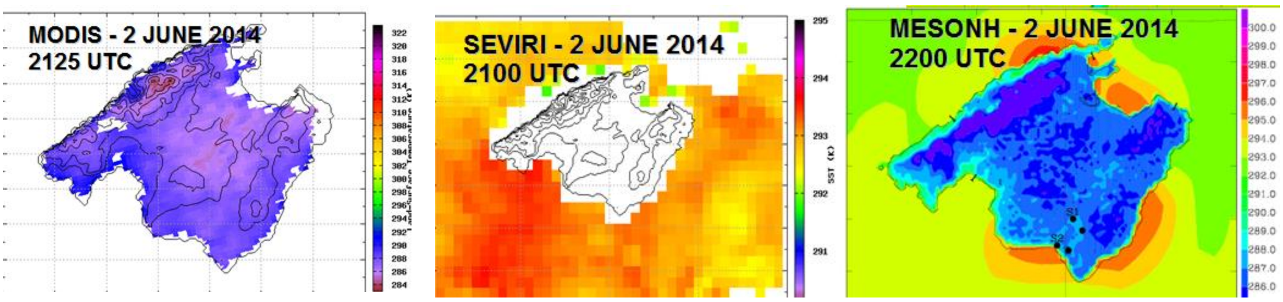


Figure 5. Satellite-derived surface temperatures compared to those obtained from the model during the evening transition sampled during IOP 3.

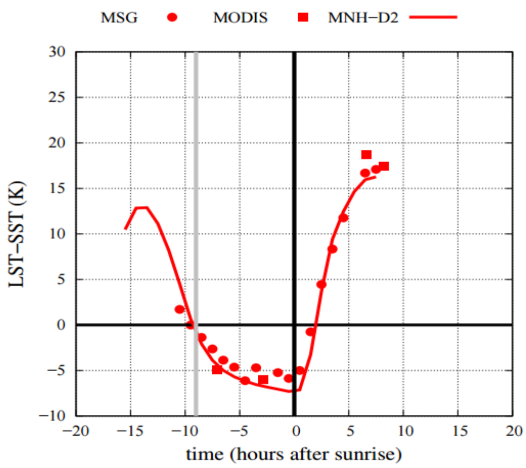


Figure 6. Modelled and satellite derived surface temperature differences between land and sea for IOP 3. The temperatures are averaged over a similar area covering: the center of the Campos basin (LST) and the bay over the sea in front of the Campos basin (SST). Time is shifted to the sunrise hour (black vertical line) and sunset is indicated with a grey line.

2) Organization of the flow at lower levels in a complex terrain valley in the central Pyrenees (La Cerdanya)

La Cerdanya is a valley located in the central Pyrenees 30 km long and 9 km wide oriented to the NE to SW directions. It is taken in this study as an example of **complex terrain valley, in terms of topography but it is also covered by heterogeneous surfaces** (forest, no vegetation, snow, …). In order to further understand the organization of the flow at lower levels, a representative case (based on the climatology of the surface weather stations of the region, Conangla et al., 2018) during fall (snow still not present at the mountains top) with a clear diurnal cycle is taken (weak pressure gradient conditions and clear-skies). A period of 48 hours, starting on September 30th 2011 is simulated with the MesoNH model with two nested domains at 2km and 400m resolution (see Figure 6).

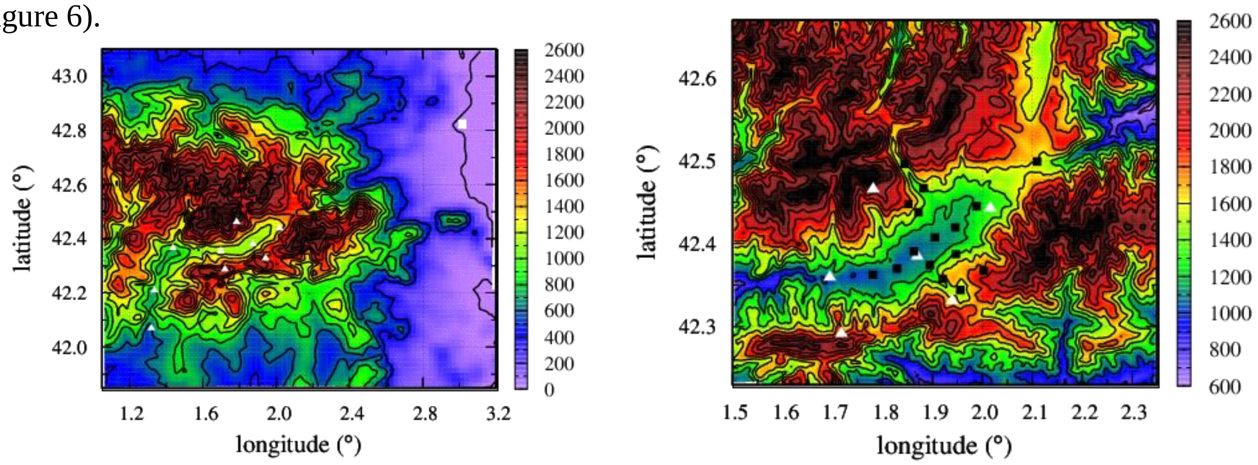


Figure 6. Topography of the two nested domains at (LEFT) 2 x 2 km and (RIGHT) 400 x 400 m resolution, respectively. The locations of the AEMET and MeteoFrance automatic weather stations are indicated in white triangles and some interesting points that we are further exploring are in black dots.

Results show that **during night-time downslope and down-valley** winds are generated and the temporal evolution of them in La Cerdanya valley strongly depends on the slope winds generated in the tributary valleys at the north and south (Figure 7, left). An opposite behaviour is reported during day time (Figure 7, right). Upslope winds are present in the northern mountains of La Cerdanya whereas those at the south are strongly influenced by the strong upslope winds generated at the south side, outside La Cerdanya. Model results are verified with satellite observations (MODIS, land-surface temperature, Figure 8) and the surface weather observations (Figure 9). It is found that **the model is able to reproduce the main observed surface temperature patterns as well as the cold pool** in the lower part of the valley (Figure 9), close to the exit (Das, labelled as DP in Figure 7). Modelled 1.5m temperatures are better reproduced in the upper valley (Figure 9, indicated as LEO in Figure 7). The model tends to overestimate the wind speed although it is capturing the turning of the wind. Further results are found in Conangla et al. (2018) where the cold pool evolution is explored through model and satellite-derived temperatures.

Now the efforts are concentrated to better understand the cold pool formation close to Das (the coldest area of the valley during night-time), a place that the climatological analysis shows the prevalence of this nocturnal process. During October 2015 an experimental field campaign was conducted to better characterize experimentally the cold pool formation close to Das (Cerdanya Cold Pool experiment 2015, **CCP15**). 4 IOPs are taken to analyse the cold pool formation through mesoscale simulations (setup similar to the previous one) and observations. Some results are shown in Figures 10 and 11 where model outputs are validated through observations (WindRass and surface energy budget station, respectively).

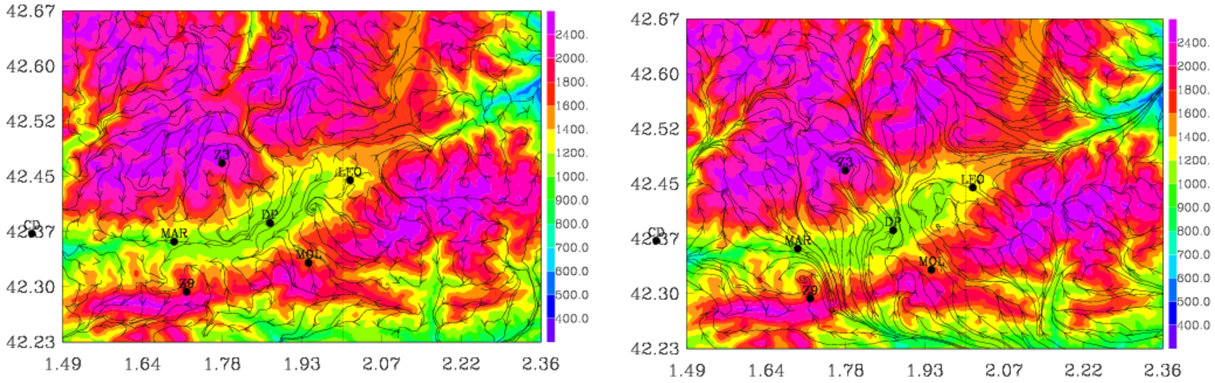


Figure 7. Streamlines at 25m (agl) together with the topography obtained from the inner domain on 1st October 2011 at (LEFT) 0200 UTC and (RIGHT) 1300 UTC.

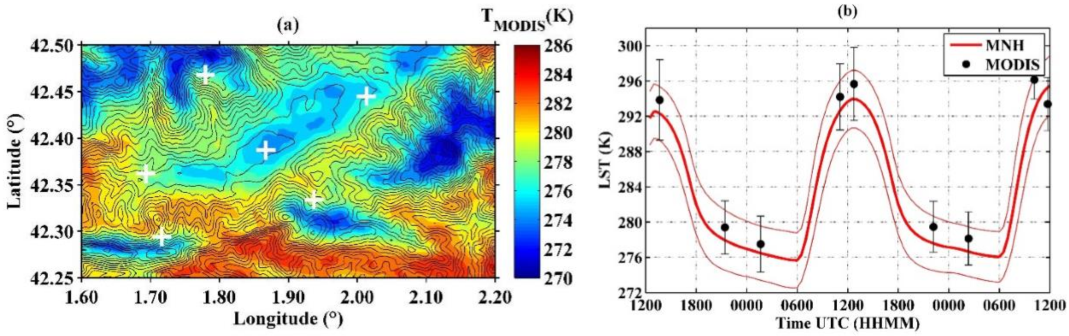


Figure 8. (a) Land Surface Temperature in a zoom inside the domain 2 derived from MODIS satellite at 2/October/2011 0220 UTC. Crosses show the AWSs location. (b) Evolution, from 30/09/2011 1200 UTC to 02/10/2011 1200 UTC, of the average surface temperature of the entire domain 2, obtained by the MesoNH model each 30 minutes (with his standard deviation), compared with the values obtained from the available nine images of MODIS satellite.

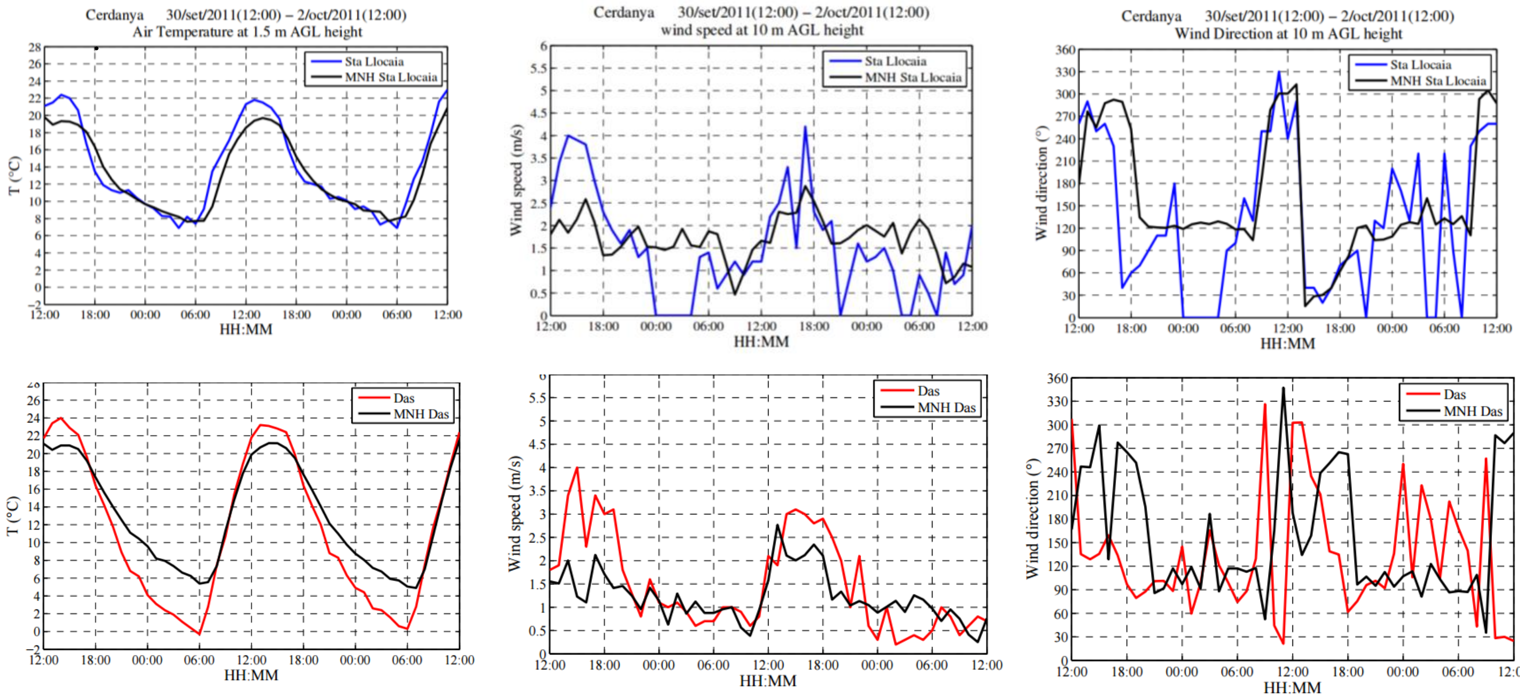


Figure 9. Modelled and observed time series (TOP) in the upper valley and (BOTTOM) in the lower valley, close to the narrow exit. These sites are indicated with LEO and DP in Figure 7, respectively.

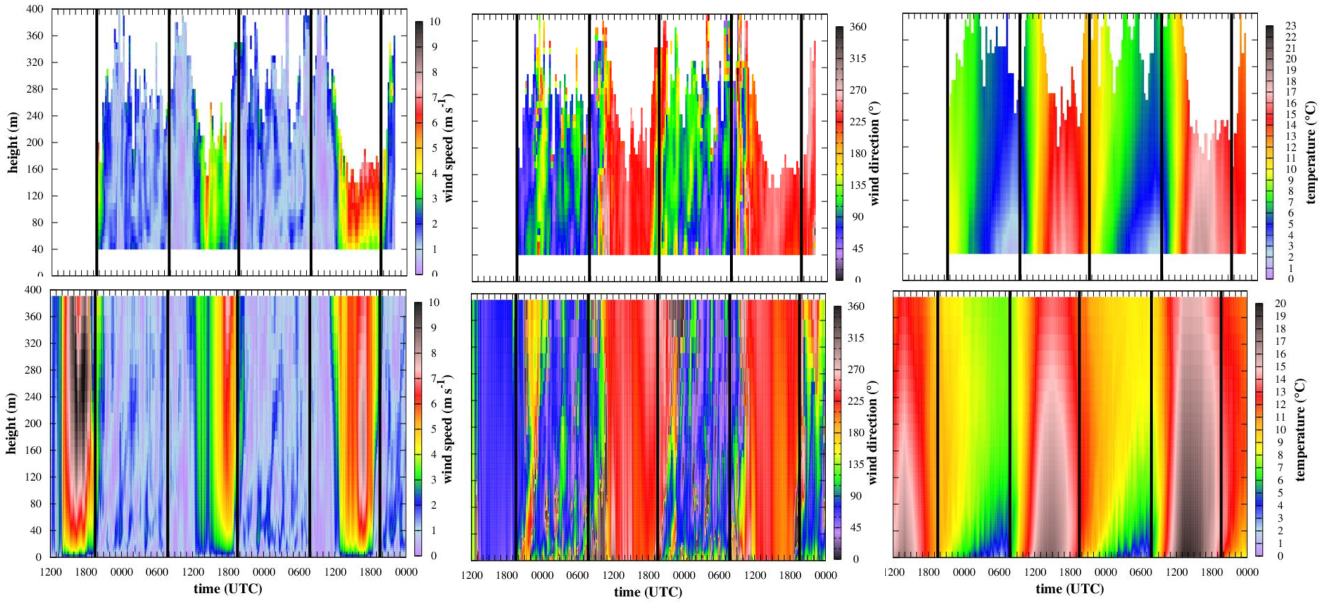


Figure 10. Time series observed by the WindRass in Das (top) together with the modelled ones (bottom) for wind and temperature during IOPs 2, 3 and 4 during CCP15 (9-11 October 2015).

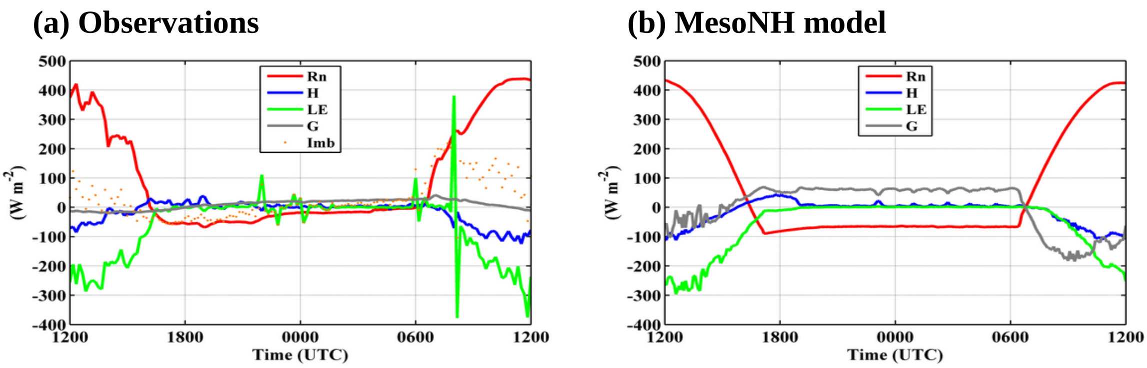


Figure 11. Time series observed and simulated surface energy balance for IOP 3 during CCP15 (10-11 October 2015).

Figure 11 points out that the model has some difficulties is reproducing some of the terms of the SEB, especially the ground flux. In MesoNH, as in other models, this term is computed imposing the imbalance as zero. However, this condition is not always fulfilled in reality and the imbalance can be of the order of magnitude of the net radiation.

During winter 2017, another experimental field campaign was conducted at this site (**CCP17**) to sample the cold pool when snow is present in the valley. The valley was more densely sampled than during CCP15 where apart from WindRass, surface energy balance station, captive balloon and multicopter, a network of observations was installed in the cold pool region. The analysis of the observations of the 10 IOPs and the preparation of the database of this campaign is still in progress. The first run consists on a 6 day period based on observations performed at the end of 2016 when a strong cold pool event was sampled, lasting for several days with no snow in the bottom of the valley but with temperatures much lower than the previous studied IOPs of CCP15.

The simulations over La Cerdanya valley based on observational available data (CCP11) and field campaigns (CCP15 and CCP17) have shown the reasons why the observations in Das (center of the cold pool) are the coldest of Catalonia. The cold pool is present during the whole year (60% of the nights), but especially in the coldest months. Different physical mechanisms are involved in its formation, such as the drainage winds generated along the valley and from several tributaries that favour the accumulation of cold air in the bottom parts of the valley, where Das is located. Besides, the model outputs show that the radiation and turbulence are the most important mechanisms within the cold pool that contribute in the evolution of the temperature at lower levels. Preliminary results are shown in Martínez et al. (2018) but it is still needed some extra analysis of these runs to get a complete picture of the processes involved during the cold pool formation and if they change along the year.

3) Downslope winds during the BLLAST experimental field campaign

The Boundary-Layer Late Afternoon and Sunset Turbulence (**BLLAST**) field campaign was conducted from 14 June to 8 July 2011 in southern France, in an area of complex and heterogeneous terrain. The main objective of BLLAST was to characterize the physical processes that take place during the afternoon and evening transitions (Lothon et al., 2014). Measurements were taken at Lannemezan (Figure 12), placed over a plateau at 600 m above sea level (a.s.l.). It is approximately 20 km north of the Pyrenees mountain range and at the exit of the Aure valley (a narrow valley, 30 km long, with the main axis oriented approximately in the north–south direction).

In the previous special project (2012-2015) mesoscale simulations were performed for the case of 1-2 July 2011 (corresponding to IOP9) to better characterize the nocturnal flow in Lannemezan. In the current special project, a total of **6 IOPs have been simulated**. They correspond to IOPs where **clear-sky and weak pressure gradient conditions** were present (see details in Table 1). Two nested domains are taken (see Figure 12) and the setup is similar to the previously simulated case 1 year before the BLLAST campaign (Jiménez and Cuxart 2014).

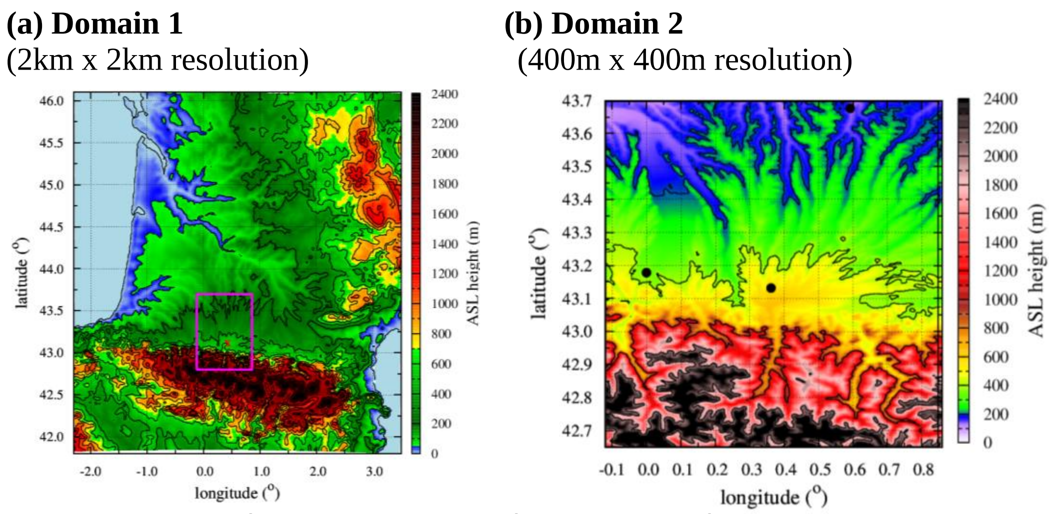


Figure 12. Topography of the 2 nested domains of the simulation of the IOPs (clear sky and weak pressure gradient conditions) during the BLLAST field campaign: The location of Lannemezan is indicated with a symbol.

IOP	Period	wind direction(*) 1300 UTC	wind direction(*) 2300 UTC	sky	Large-scale circulation(**)
1	15-16 June	N	-	clouds and rain	weak winds, not clear direction
2	19-20 June	N	low S	clear skies,light rain	high-pressure, weak E wind
3	**20-21 June**	E	low S	clear skies	high-pressure, weak NE-E wind
4	24-25 June	-	E/S	clouds only during day	Atlantic high-pressure, strong NE-E winds
5	**25-26 June**	E	E/S	clear skies	Atlantic high-pressure, strong NE-E winds
6	**26-27 June**	E	E/S	clear skies	Atlantic high-pressure, winds from N-E
7	27-28 June	-	-	clouds	strong E winds
8	30-1 July	-	-	clouds and rain	strong N winds (fronts)
9	**1-2 July**	N	E/S	clear skies	Atlantic high-pressure, weak NE winds
10	**2-3 July**	N	E/S	clear skies followed by clouds	Atlantic high-pressure, weak NE winds
11	**5-6 July**	N	W	clear skies	Atlantic high-pressure, weak S winds

(*) extracted from the soundings within the BL extend (about 1000 m agl). Slope wind directions in Lannemezan: upslope (N) and downslope (S).
(**) corresponding to the surface level. At higher levels winds were from W for all the IOPs.
(-) indicates no sounding.

Table 1. Description of the different IOPs during the BLLAST experimental field campaign and in bold those studied in depth with mesoscale modelling.

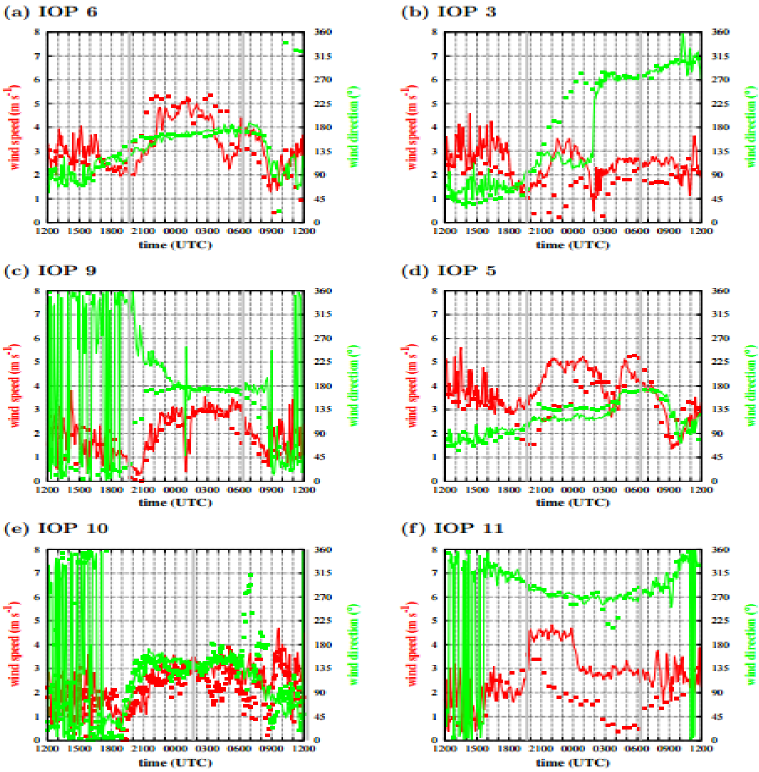
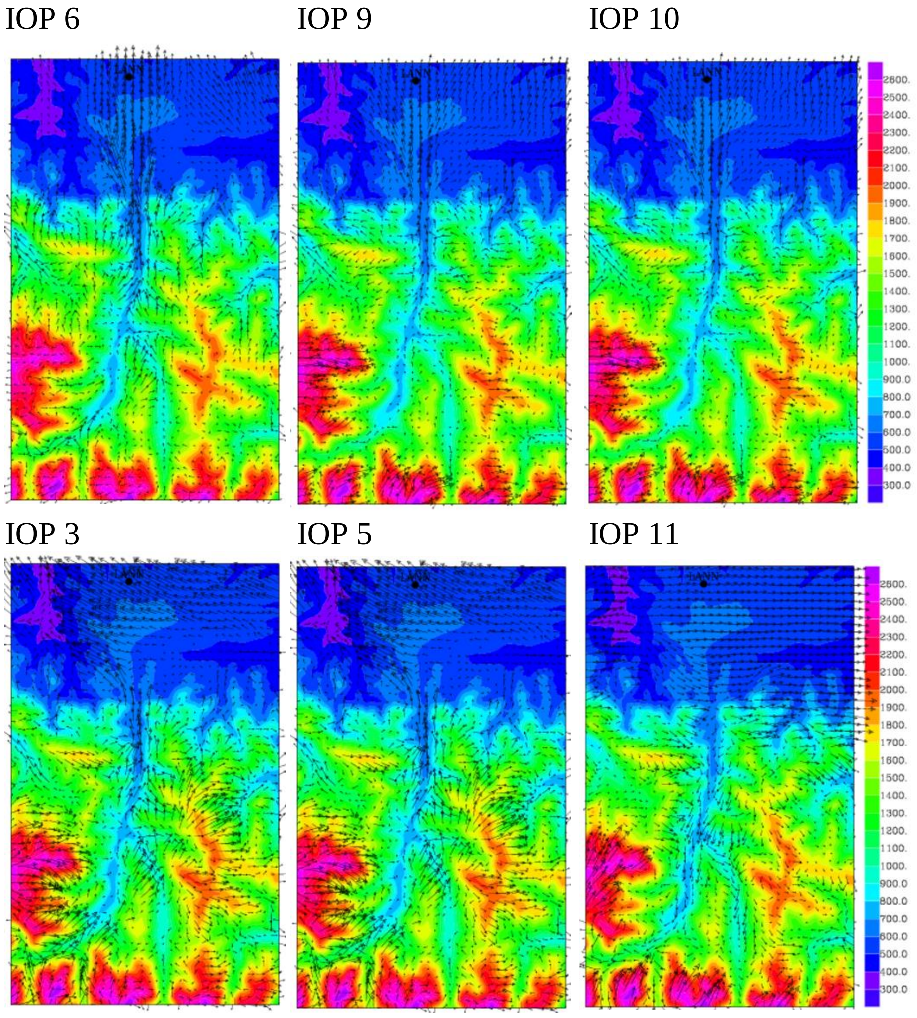


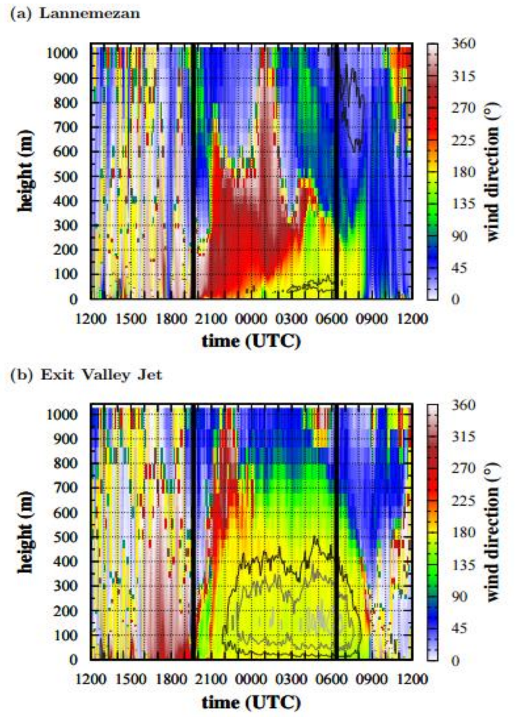
Figure 13. Verification of the runs for the different IOPs during BLLAST for the modelled and observed wind at 15 m AGL. Further details of the IOPs in Table 1. On the (LEFT) the IOPs were southerly winds were reported in Lannemezan (corresponding to the downslope direction) and on the (RIGHT) cases when winds in Lannemezan were not from south during most of the night.



CASES WITH DOWNSLOPE WINDS

OTHER CASES

Figure 14. Wind vectors at 50m AGL and topography (in colours) for an area covering the Aure valley and the plateau where Lannemezan is placed. At the TOP the IOPs with nocturnal downslope circulations and at the bottom other cases.



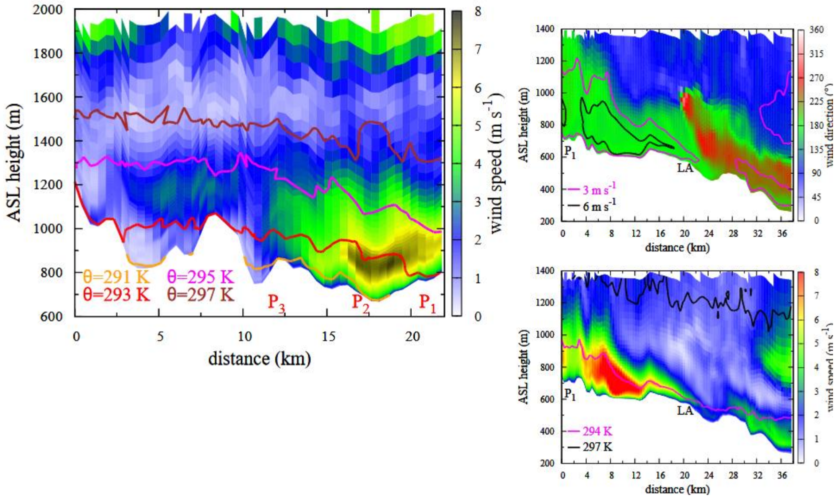


Figure 16. Vertical cross-sections along the Aure valley (top) and from the exit of the Aura valley towards the foothills at 0400 UTC for IOP 9.

Figure 15. Temporal evolution of the vertical profiles of the wind direction (in colours) and speed (in grey-scale lines, black 4m/s) for IOP 9 in (a) Lannemezan and (b) at the exit of the Aure valley.

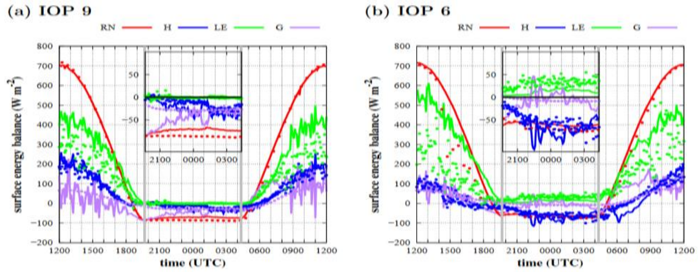


Figure 17. Modelled and observed evolution of terms of the SEB for IOPs 6 and 9.

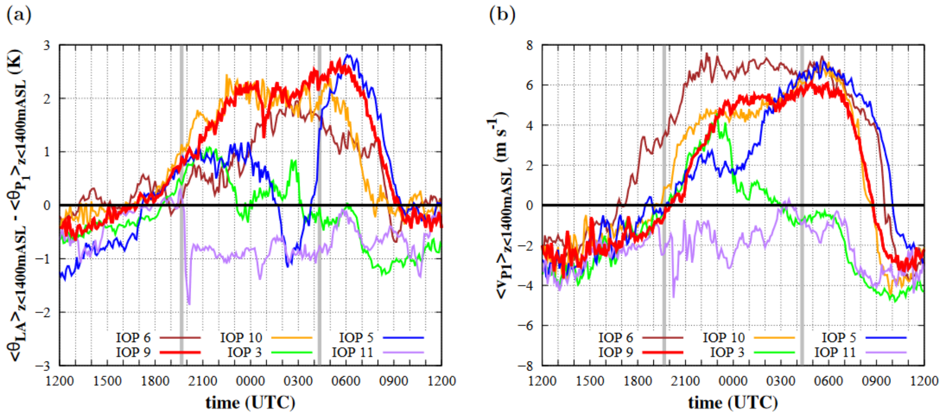


Figure 18. (a) Time series of the difference of the vertically-averaged (from the ground up to 1400 m ASL) potential temperature between Lannemezan (LA) and the exit of the Aura Valley. (b) The same as (a) but for the averaged v-component v-component of the wind at the exit of the valley. The vertical grey lines indicate sunset and sunrise instants and the black horizontal one shows the position where the wind or the temperature difference are zero.

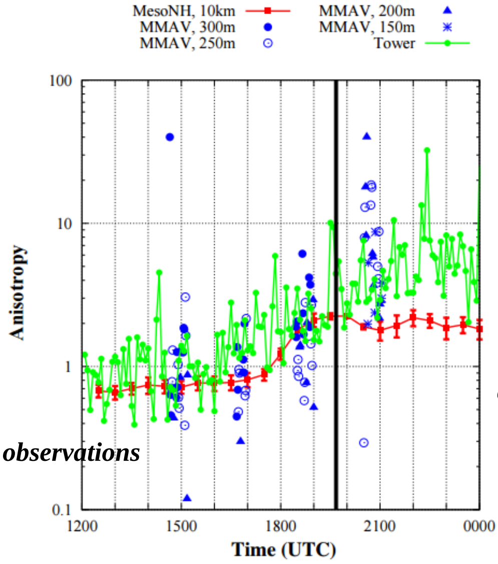
The aim of the current work is to better describe the **dynamics of the Aure valley** (there are not available observations) and its influence on the atmospheric boundary layer at the foothills, where the CRA observatory is located (Lannemezan). The model results are useful to describe the main features of the nocturnal exit valley jet and the ambient conditions that favour its formations. This jet is typically generated due to the accumulation of downslope and downvalley winds at the exit of a valley, as it is described in Whiteman (2001). Simulations have shown that the observations in Lannemezan are strongly influenced by the presence of this valley exit jet.

Model results are validated with observations in Lannemezan since there are no available observations inside the Aure valley. For all simulated IOPs the model is able to reproduce the wind speed and direction in Lannemezan (Figure 13) as well as the temperature patterns (not shown). During the night-time, most of the IOPs present southerly winds in Lannemezan (corresponding to the downslope wind direction). However, for **IOPs 3 and 11 the large-scale winds did not allow the development of these slope circulations** and the wind direction during the night was from SE (veering to W) and W, respectively. Particularly, for IOP 5 wind direction was mainly from E during most of the night but it veered to S at about 0300 UTC, when the strong easterly wind weakened (Figure 14). The rest of simulated IOPs (6, 9 and 10) behave similarly and **downslope winds were present during the whole night** (southerly wind direction, Figure 14), in agreement with observations.

From the analysis of the model results it is found that an **exit valley jet** is generated in the Aure valley during night-time for the studied cases (see for instance Figure 16), except for IOP 11 (see details in Table 1). Its main features depend on the ambient conditions such as the wind speed and direction of the synoptical or mesoscale winds at the foothills of the Pyrenees. The exit valley jet reaches Lannemezan (Figure 16) if large-scale winds at the foothills are weak or if they are moderate or strong when they diminish. Model results show that the exit valley jet weakens and lower when it travels from the exit of the valley towards the foothills, where Lannemezan is placed; interacting with the locally-generated flow at these sites (Figures 15 and 16). Besides, the terms of the SEB also depend on the features of the jet once it reaches Lannemezan (Figure 17). The model outputs are further analysed to better understand the physical mechanisms involved in the exit jet formation. It is found that downslope winds are generated at the mountain slopes close to sunset. They converge to the central part of the bottom of the valley and the exit jet is generated about 2-3 hours afterwards due to the accumulation of air in the narrow pass close to the exit of the valley. As it is seen in Figure 18, the thermal gradient between the exit of the valley and the plain enhances the propagation of the jet through the foothills.

IOP 10 is further analysed (Lampert et al., 2016) because the turbulence properties of the lower atmosphere (up to 300 m above ground level) were sampled with the **Meteorological Mini Aerial Vehicle (M^2AV)** from turbulently mixed to stably stratified atmospheric conditions. IOP 10 is similar to the previously described IOP 9. However for IOP 10 a **low-level jet was formed during the evening transition due to the interaction between the large-scale winds and the locally-generated downslope winds** (Figure 13b). It is found that during the AET the **anisotropy** of the turbulent eddies increases as the vertical motions are damped due to the stably stratified conditions (Figure 18a) and this effect is enhanced by the formation of a low-level jet after sunset (Figure 18b).

The simulations based on BLLAST IOPs (further described in Jiménez et al., 2018) have shown the importance of the valley exit jet in the evolution of the atmospheric boundary features in Lannemezan (at the exit of the valley, 10 km away in front of the exit of the valley). Results have shown that most of the nights this jet is generated at the valley and, if the background winds at the foothills are weak or from the south, it reaches Lannemezan. Model results at 400 m resolution agree with the observations, pointing that this horizontal resolution is enough to capture the organization of the flow at lower levels. In the next special project it is expected to evaluate if the circulations within the valley are realistic, performing mesoscale simulations of cases based on an experimental field campaign that it is currently going on.



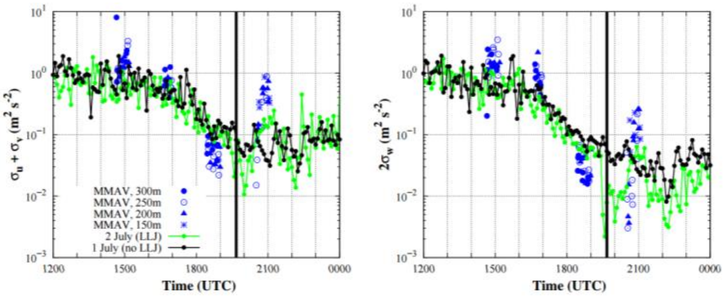


Figure 18b. The same as a but for the (LEFT) horizontal $\sigma_u + \sigma_v$ and (RIGHT) vertical $2\sigma_w$ variances computed from the tower observations at 60 m AGL during IOP 9 (without an LLJ, black line) and IOP 10 (with an LLJ, green line), together with those derived from M^2AV observations

Figure 18a. Time series of the anisotropy computed from different sources: (1) M^2AV flight observations at 150, 200, 250 and 300 m a.g.l. during the four flights, each symbol representing a particular height (in blue); (2) tower measurements at 60 m a.g.l. every 5 min covering the afternoon–evening transition (in green); (3) model results averaged between 150 and 300 m a.g.l. to be close to the altitudes of the M^2AV observations considering a spatial area of 10 km × 10 km centred at Lannemezan (in red). The time of sunset is represented by a black vertical line. Note the logarithmic scale on the y axis. For M^2AV, $\sigma^2_u = \sigma^2_v$ is assumed.

Concluding remarks

To increase the understanding of meteorological circulations over complex heterogeneous terrain is a necessity that cannot be solely undertaken by either numerical modelling or through increased experimental observation. Instead it has to be a combination of both methods since the former may provide solutions that diverge from reality and the latter may not provide enough information to have an integral view of the relevant processes taking place. Our group combines both approaches and this would not have been possible without the sustained support provided by ECMWF and AEMET to use the computing time, storage and support during the duration of the project, also with the exceptional support of the Meso-NH team at CNRM and LA in the maintenance of the code at these facilities. Analysis and validation of the simulations would neither have been possible without the data gathered, many times in difficult conditions, by our colleagues in the field, that are also warmly acknowledged in this final report.

List of publications/reports from the project with complete references

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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.)

During the following special project (2018-2020) we will continue exploring the mesoscale simulations already made for CCP'15 and CCP'17, without snow, and new simulations for the cases with snow in CCP'17 will be completed. They are based on observations and further work is needed to complete the analysis and to understand the most relevant physical processes that take place in these complex areas, with special attention to the cold pool formation. Regarding the simulations related to the BLLAST IOPs, numerical and results have shown the presence of a valley exit jet that reaches Lannemezan (about 20km from the exit of the valley) after midnight. From the BLLAST database is not possible to validate the modelled organization of the flow inside the valley because there are not available observations. Since May until September 2018 an experimental field campaign is conducted and some observations are made inside the valley and at the exit through surface stations and Lidar to sample the valley jet features. New mesoscale simulations will be done (of some selected IOPs) to check the performance of the model in reproducing this jet features. Finally, the Subpixel experimental campaign was held in the University Campus in Mallorca in 2016 that has provided dense experimental information at the hectometer scales, both in situ and by remote sensing, and a challenge will be to define and execute the numerical simulations corresponding to the selected cases.