Cold-air pooling in the Cerdanya valley (Pyrenees)

D. Martínez-Villagrasa[1*], L. Conangla[2], G. Simó[1], M. A. Jiménez[1], D. Tabarelli[3], J. R. Miró[5], R. Picos[1], A. López[1], D. Zardi[3] and J. Cuxart[1]

[1]Meteorology Group, Universitat Illes Balears, Palma, Mallorca. [2]Dept. of Applied Physics, Universitat Politècnica de Catalunya, Manresa, Barcelona. [3]University of Trento, Italy. [4]Servei Meteorològic de Catalunya (METEOCAT), Barcelona.

*e-mail address: dani.martinez@uib.cat

INTRODUCTION

CERDANYA VALLEY

- The largest of the Pyrenees (35 km x 15 km)
- NE-SW orientation.
- Bounded by Pyrenees main axis (peaks > 2900 m asl(*)) to the north and the Cadí mountain range (maximum height 2913 m asl) to the south.
- Valley bottom (1000 m asl) covered by grass and pastures, forests of conifers (southern slopes) and alpine pastures (northern side).
- Smaller tributary valleys oriented in the N-S direction.

(*)Above sea level.

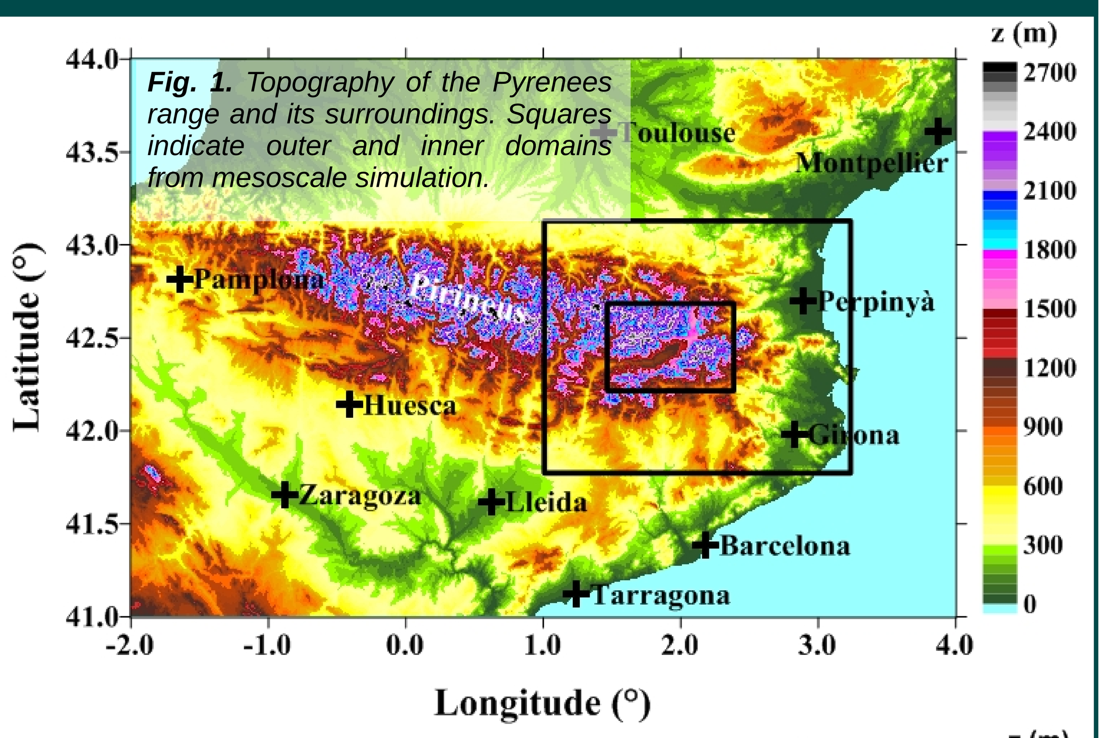


Fig. 1. Topography of the Pyrenees range and its surroundings. Squares indicate outer and inner domains from mesoscale simulation.

OBSERVATIONS

Source: 6 AWS (fig 2):

- 3 AWS along the main valley axis:
  - Martinet (**MR**): Valley end, narrower (1038 m asl).
  - Das (**DA**): wide + flat area (1097 m asl).
  - Sta. Llocaia (**SL**): Valley head (1320 m asl).
- 1 AWS at the upper part of a tributary valley (south-east of DA): La Molina (**LM**, 1704 m asl).
- 2 AWS at valley crests:
  - Cadí Nord (**CN**): south (2143 m asl).
  - Malniu (**ML**): north (2230 m asl).

Variables: Temperature (T), relative humidity (RH) at 1.5 m height, wind speed (WS) and wind direction (WD) at 10 m height (6 m for ML) + insolation (Q) at DA.

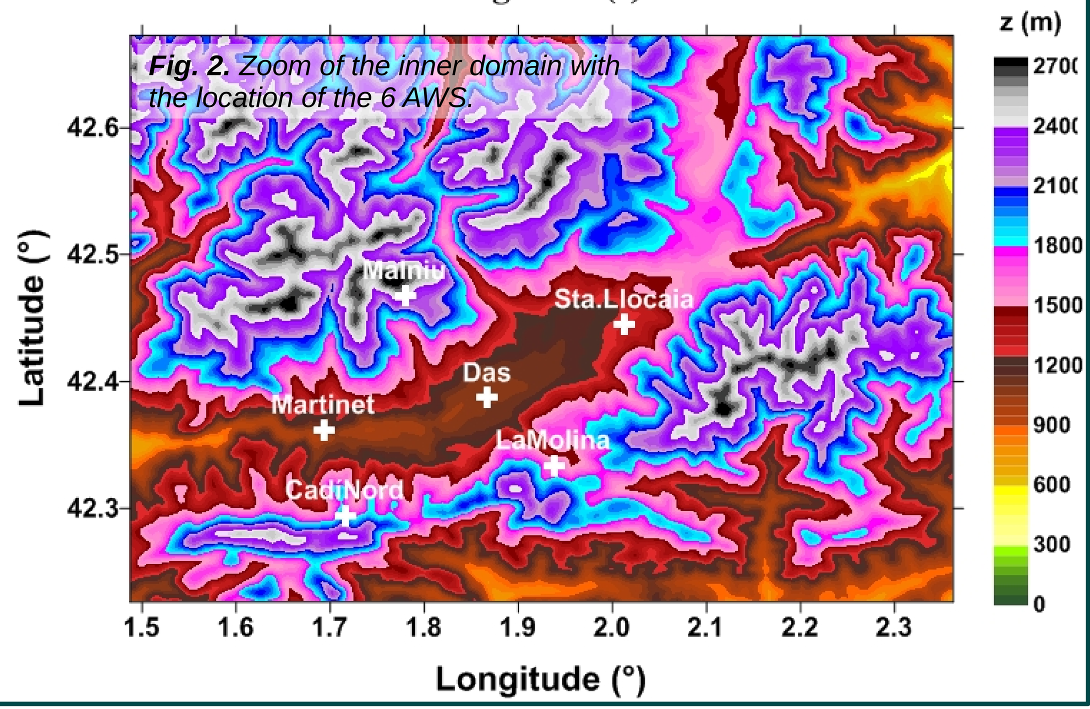


Fig. 2. Zoom of the inner domain with the location of the 6 AWS.

COLD-AIR POOL (CAP) STATISTICS

Period: 01/09/2010 — 31/08/2014

CAP definition: Temperature difference between DA and SL must be below – 3 K during at least 2 h: T_{DA}-T_{SL} ≤ - 3 K.

Note: DA is taken as the reference value inside the CAP since it is the station with lowest nocturnal T (see next section) and closest to SL .

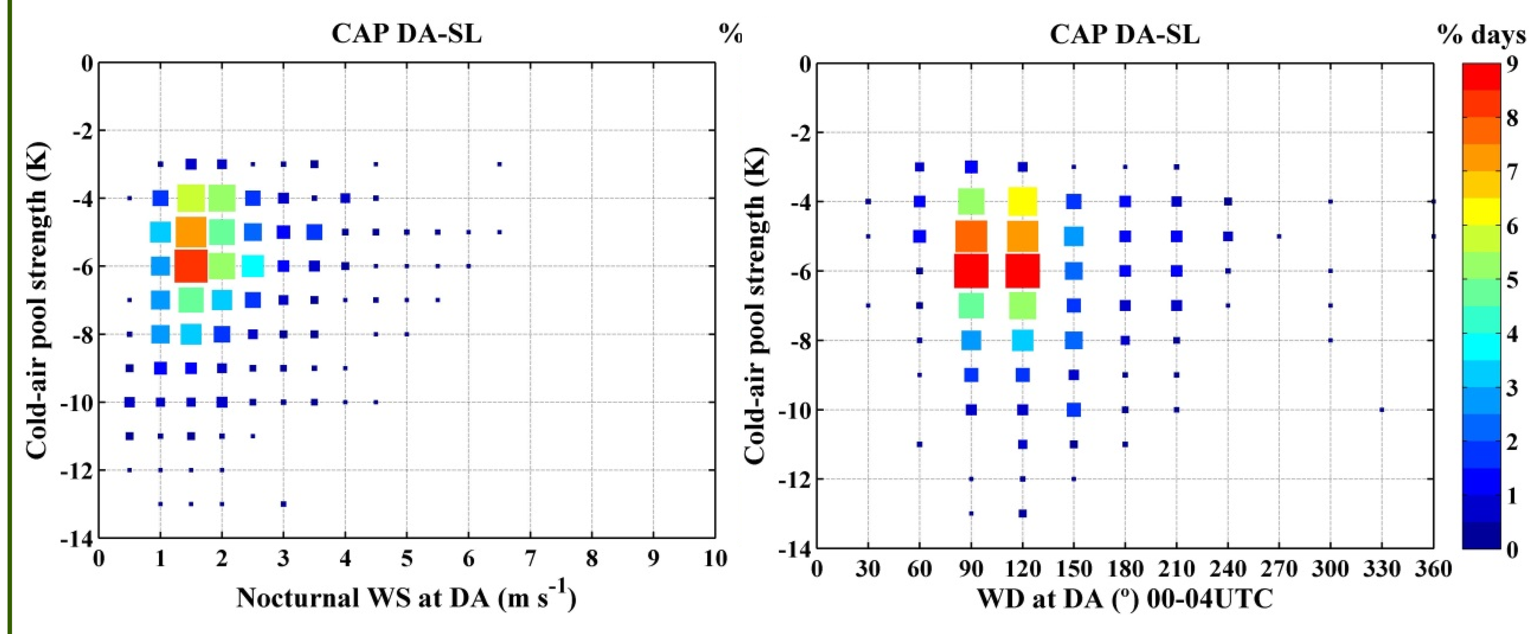


Fig. 3. Bivariate histogram of CAP cases as a function of CAP strength and nocturnal [left] wind speed or [right] wind direction at DA. Nocturnal wind is the mean value obtained between 00 and 04 UTC.

- 59% of the nights with daily CAPs.
- 70% with T_{DA}-T_{SL} ≤ - 5 K and 5% ≤ - 10 K
- Daily CAPs persist more than 5 h (13h in January)..
- Wind speed is low within the CAP.
- Wind direction is down-valley often perturbed with drainage flows from southern tributary valleys.

STATISTICAL DIURNAL CYCLE

Selection of stable nights. A filter is applied to DA time series to select those cases with clear skies and weak synoptic pressure gradients (Martínez et al., 2008). Indexes' thresholds have been adapted to valley dynamics. Only days from **March to October** are considered to avoid snow events. The filtered dataset contains **163 days** from a total of 980 (17%).

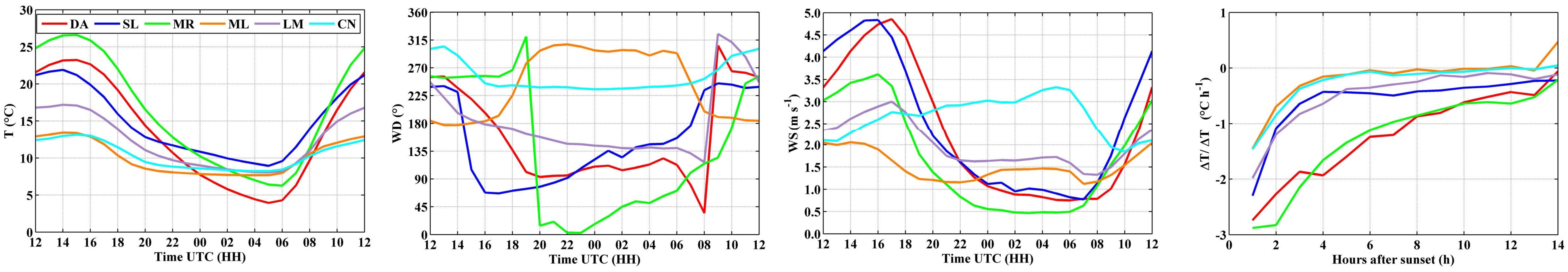


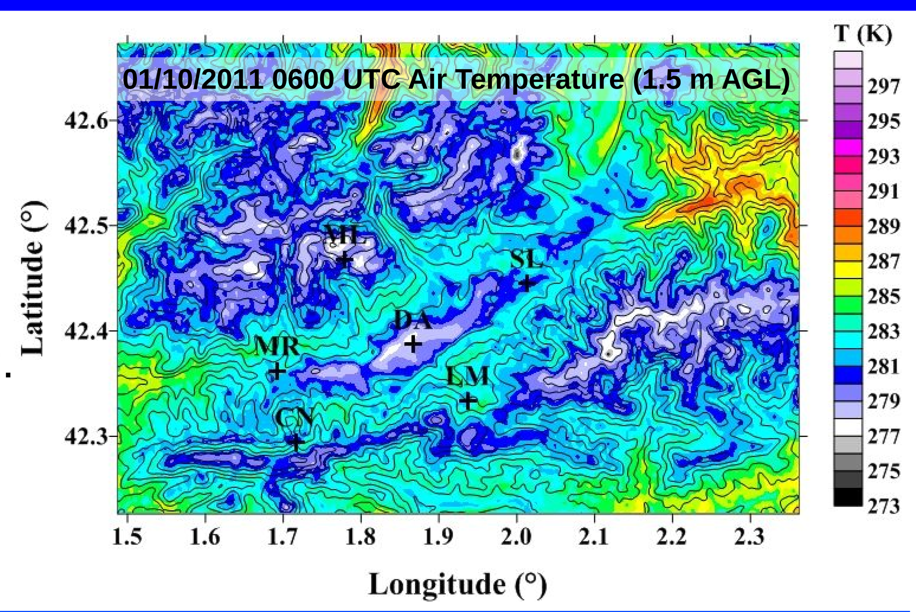
Fig. 4. [From left to right]. Daily cycle of the average temperature, wind direction and speed measured at the six AWS for the selected 163 days. Rightmost panel shows the hourly nocturnal cooling rate.

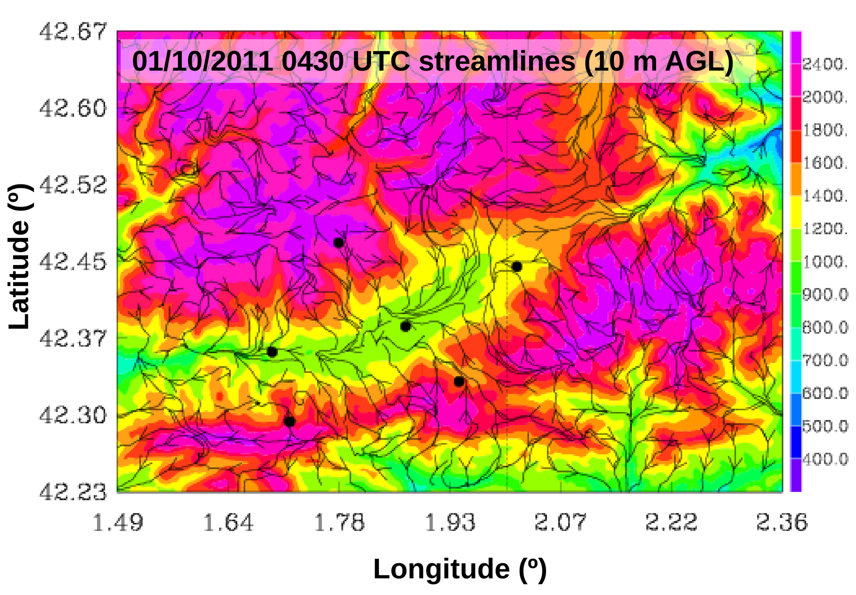
- Statistical data show a valley regime with a diurnal cycle within the Cerdanya valley.
- Large amplitudes of T at the valley floor (MR, DA), smaller at the valleys head (SL and LM) and smallest at valley crests (CN, ML).
- DA attains the lowest T_{min} (1.6 K below MR) and SL measures the highest. A small hill between DA and MR blocks the down-valley flow, favoring a more intense cooling at this part of the valley floor (see next section).
- Nocturnal cooling rate is much larger at the valley floor.
- Steady down-valley winds at DA, while the nocturnal wind turns at the valley end (MR) and head (SL) due to other valleys' influence
- LM reflects the dynamics of down-valley at night and up-valley at the beginning of daylight.
- At high-altitudes (CN, ML), westerly wind has an in-(out-)valley component at night (day)
- Wind speed is minimum during the night-day transition regime for all stations.

MESOSCALE SIMULATION

Meso-NH model (Lafore at al., 1998) with **two nested domains.**

- Horizontal resolution: 2 km and 400 m.
- Stretched vertical resolution: **3 m close to the ground** and 8 m at 500 m height.
- Initial and lateral boundary conditions: ECMWF analysis every 6 h. One way nesting for domain 2.

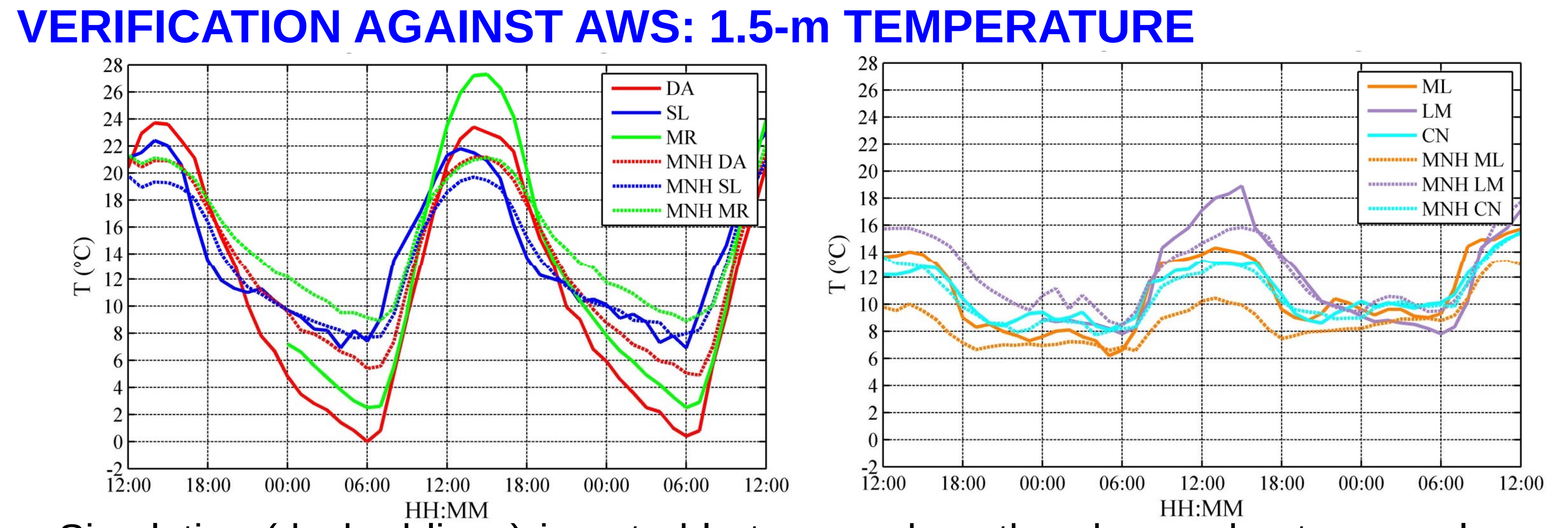




A 48-h long case study **(12 UTC 30/09/2011 – 12 UTC 02/10/2011)** is selected from the list of 163 days. Observations reflect a similar pattern to the statistics, with wind speeds generally very low at night and a **strong temperature inversion** generated within the Cerdanya valley.

- Streamlines at the valley floor show the influence of tributary valleys (northern tributaries at MR, and southern tributaries at DA and SL) that disturb the down-valley regime.

VERIFICATION AGAINST AWS: 1.5-m TEMPERATURE



- Simulation (dashed lines) is not able to reproduce the observed extreme values within the CAP (MR and DA, **differences ≤ 6 K**).
- Results more accurate at the head valley (SL) and at the mountain crests.

VERIFICATION AGAINST SATELLITE

- On average, simulated surface temperature field matches with MODIS satellite observations.
- Generally, MODIS product gives higher values than the model, specially at the mountain peaks.

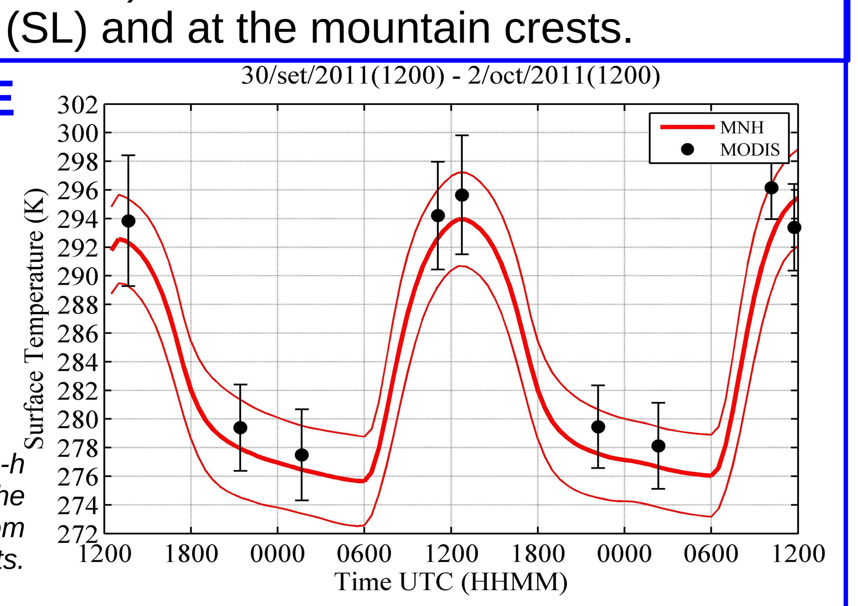


Fig. 5. Domain-averaged surface temperature evolution for the 48-h cycle obtained from the model output every 30 minutes (and the respectively standard deviation) compared to the values obtained from MODIS satellite images at 9 instants.

CAP evolution

The simulated temperature fields at the surface and at 1.5 m are decomposed in three terms (Lundquist et al., 2008; Martínez et al.,2010):

$$T(\vec{x},t)=\overline{T}(\vec{x})+\langle T\rangle(t)+\tilde{T}(\vec{x},t)$$

(1) (2) (3)

Fig. 6. Valley-average cooling term (2): Large differences between cooling at the surface and at 1.5 m height probably due to the windless situation.

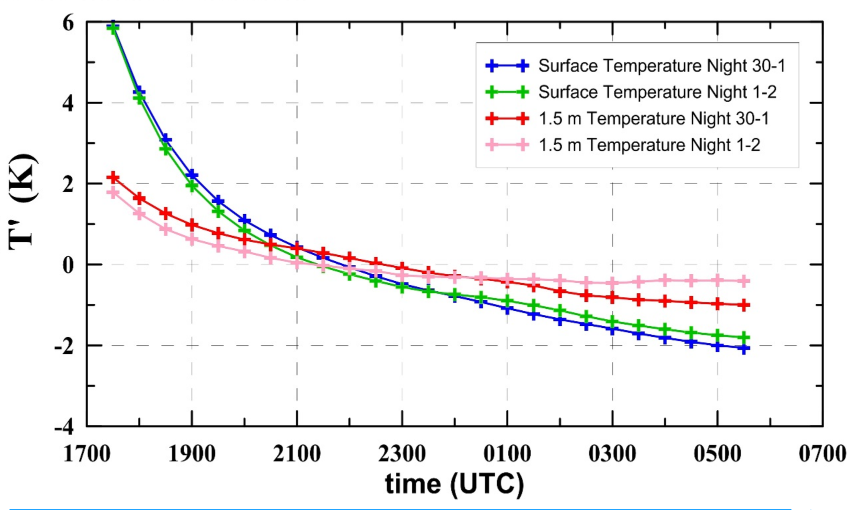
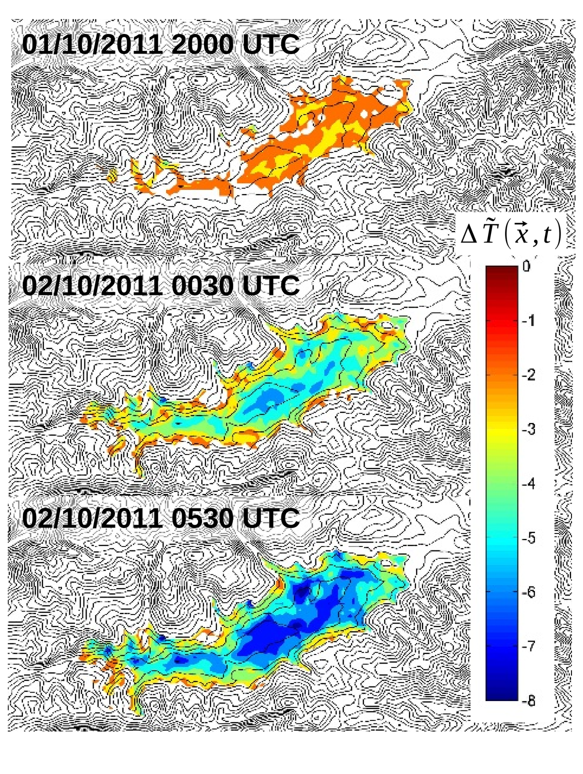


Fig. 7. Difference between term (3) at three different times of the night (1-2 Oct 2011) compared to the value at the beginning (1730 UTC). Only data with negative results within the Cerdanya valley are given.

Local spatial deviation term **(3)**: used to illustrate the evolution of those areas with a stronger cooling.

- Two CAPs form at the beginning of the night. Upper-valley CAP forms first and is colder.
- Both CAPs merge when their depths overtake the small hill between them.



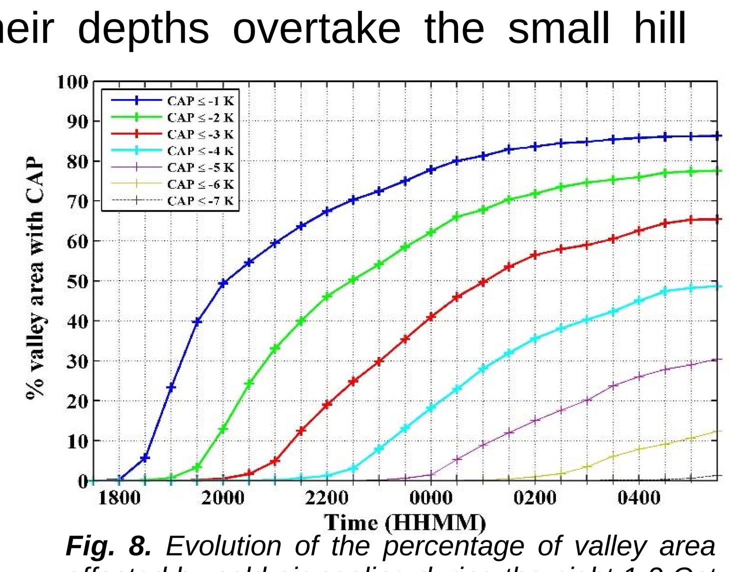


Fig. 8. Evolution of the percentage of valley area affected by cold-air pooling during the night 1-2 Oct 2011 considering different thresholds for $\Delta\tilde{T}(\vec{x},t)$.

- CAP area evolution depends on the threshold used for term (3).
- Hardly a 50% of the area analyzed cools more than 4 K respect to the mean cooling of the basin.

CONCLUSIONS

- A recurrent daily cold pool develops over the Cerdanya valley, which has been studied statistically through 4-year time series from 6 AWS distributed around the area.
- Drainage flows from tributary valleys disturb the down-valley regime, providing local singularities.
- A mesoscale simulation is able to reproduce the general features of valley wind circulations and cold air pool formation, but shows limitations in reproducing the cold pool strength.

Further Work: Analysis of the experimental campaign performed in October 2015, which provided vertical profiles of atmospheric variables and surface energy budget terms at DA.

References

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