WRF simulations of upslope and downslope flows over the Guadarrama mountain range (Spain)

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1. SLOPE FLOWS

Under weak synoptic pressure gradients and clear sky, the thermal patterns over mountainous terrain generate some characteristic circulations [1]:

Anabatic (upslope) winds during the day

Katabatic (dowslope) winds during the night

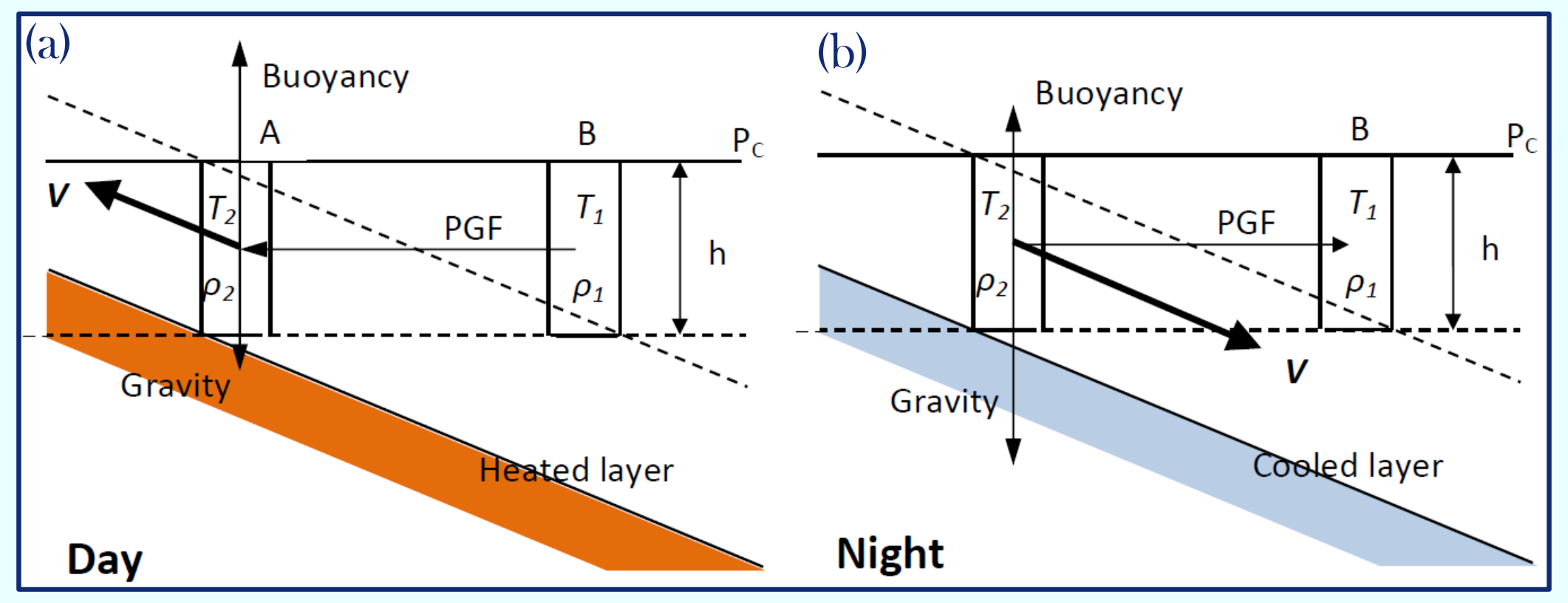
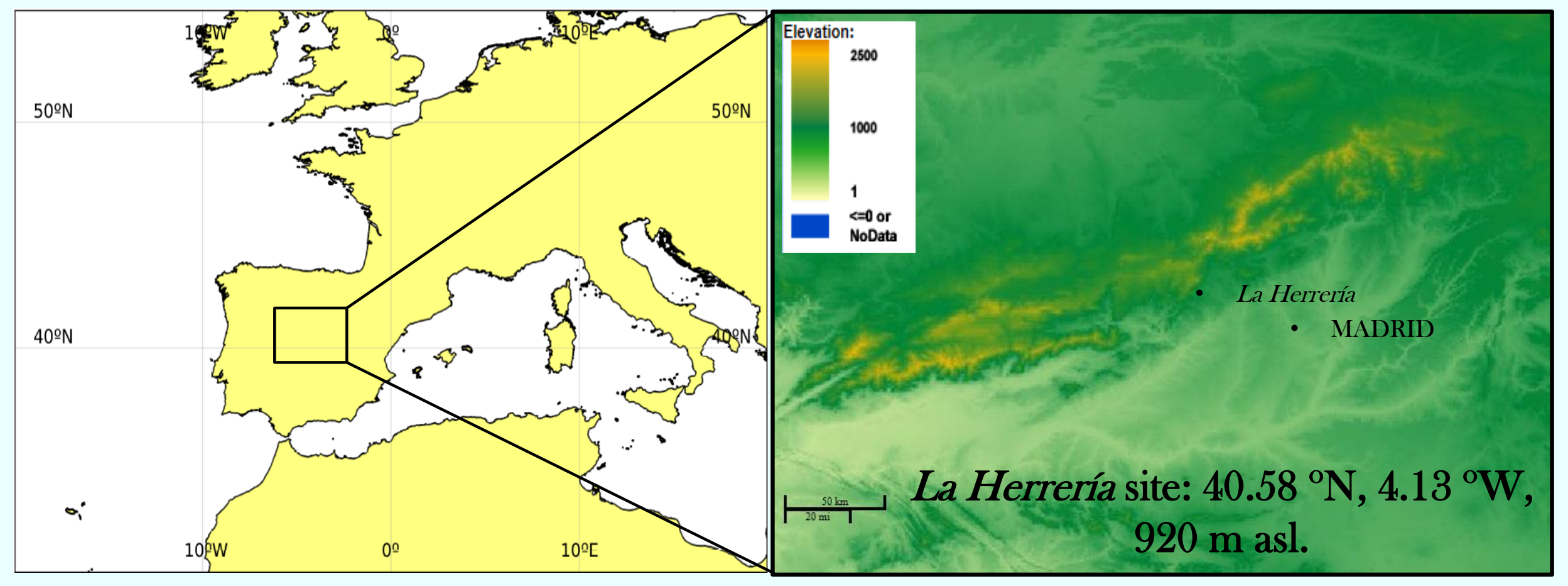


Figure 1. Schematic representation of the forces involved in (a) anabatic and (b) katabatic winds [2]. The air temperature in columns A and B determines the density and consequently the pressure-gradient force (PGF).

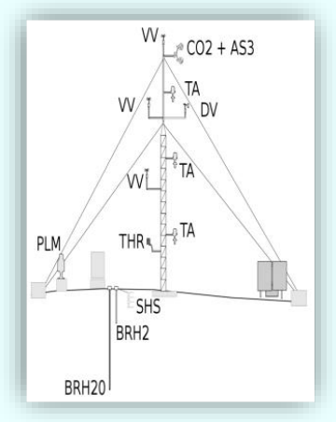
MOTIVATION
- Interaction with other mesoscale circulations [3].
- Downslope flows - gravity waves - turbulence interactions [4].
- Influence on CO_2 and $(H_2O)_v$ turbulence fluxes [5].

2. LA HERRERIA SITE



La Herrería site: 40.58 °N, 4.13 °W, 920 m asl.

Figure 2. Location of *La Herrería* site and the city of Madrid (Spain). The source of topography data is ASTER GDEM (METI, NASA).



Recently installed micrometeorological instrumentation at 10 m + 4 m portable tower.

CO_2 and $(H_2O)_v$ turbulent fluxes + energy and CO_2 budget

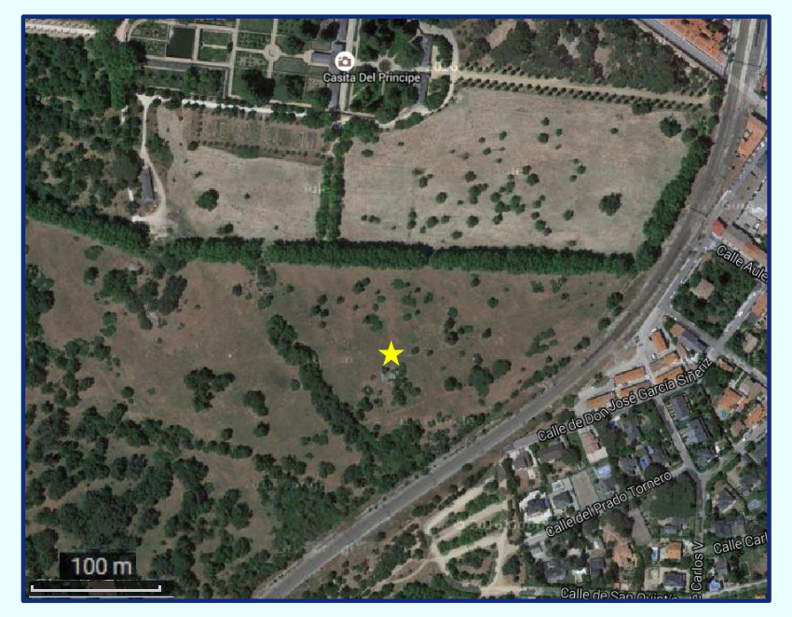


Figure 3. Aerial photography of the surroundings of *La Herrería* site (yellow star), obtained from *Google Maps.*

For more information see **Poster nº 129** (Poster Session 2).

3. WRF MODEL

MODEL	WRF-ARW VERSION 3.5.1
INITIAL AND BOUNDARY CONDITIONS	NCEP FNL (1° x 1°, 6h)
HORIZONTAL RESOLUTION (km)	4 nested domains (27; 9; 3; 1)
VERTICAL RESOLUTION	51 eta levels (9 in the first 100 m)
TIME STEP	81 s
SPIN-UP TIME	12 h
SURFACE PHYSICS	Noah LSM

Table 1. WRF-model settings.

4 different simulations:

PBL & SURFACE LAYER	SIM. NAME
YSU + MM5	*ysu_mm5*
YSU* + MM5	*ysu*_mm5*
MYNN2 + MM5	*mynn2_mm5*
MYNN2 + MM5*	*mynn2_mm5**

Table 2. Sensitivity experiments.

YSU = YSU + topowind*
MM5 = Revised MM5*

4. SIMULATED SLOPE FLOWS AND FOOTPRINT ESTIMATION

A period of almost steady synoptically-stable conditions is simulated: **16-22 May 2016**.

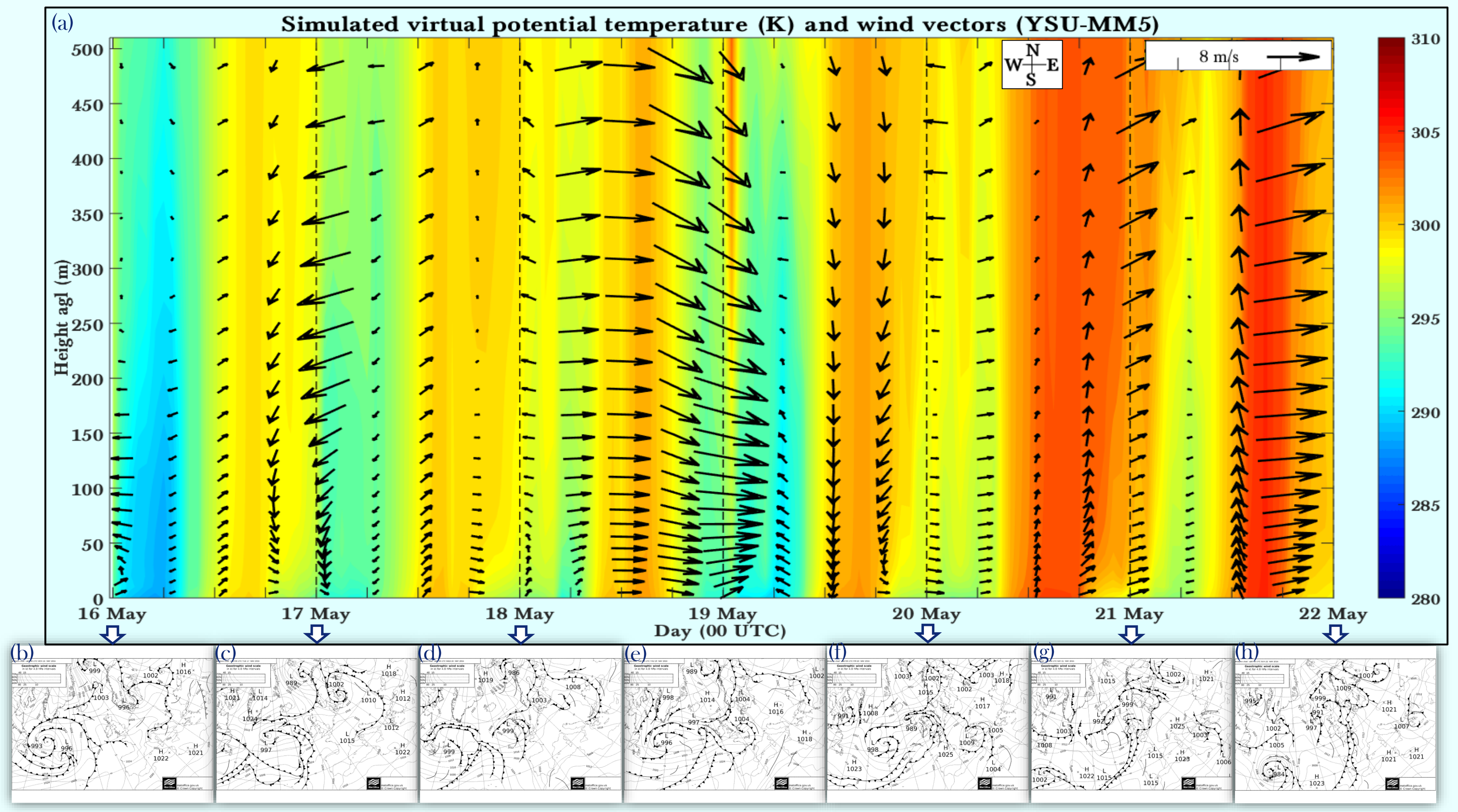


Figure 4. (a) Temporal evolution of the vertical profile of the simulated virtual potential temperature and wind vectors at the grid point of *La Herrería* site during the selected period for the *ysu_mm5* simulation. (b-h) Daily surface-pressure charts for the selected period from Met Office, obtained from Wetterzentrale (www.wetterzentrale.de).

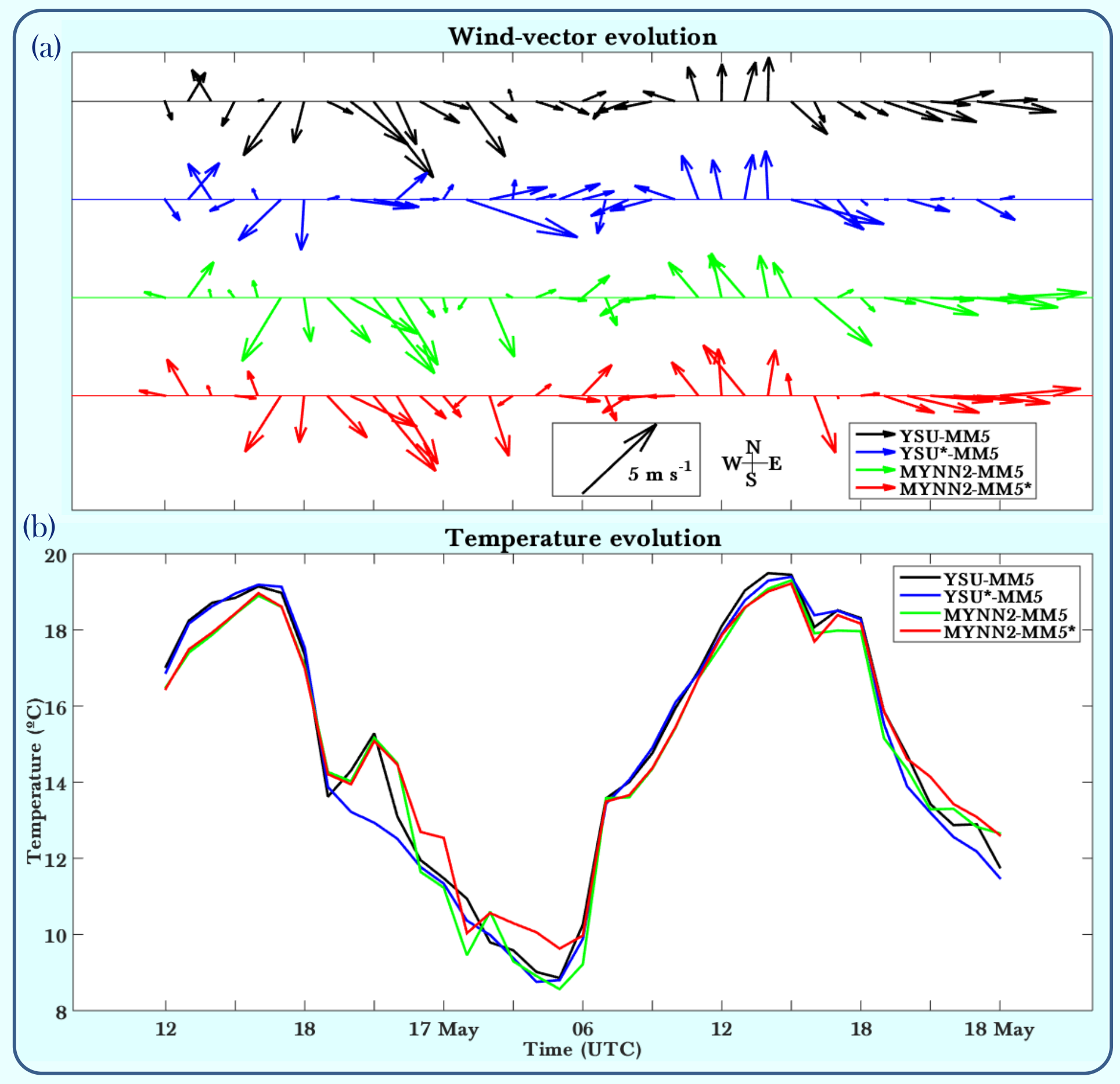


Figure 5. Time evolution of the (a) 10-m wind vectors and (b) 2-m temperature for the four simulations at *La Herrería*, from the 16/05 at 1200 to the 18/05 at 0000.

The anabatic-katabatic transition is clearly identified during May 16th-18th. This is less clear in the ysu*_mm5 simulation due to the high variability of the wind.

How do the slope flows affect the **turbulence** and the estimation of the **footprint**?

TKE BUDGET:

$$\boxed{\frac{\partial e}{\partial t}} = \boxed{\frac{g}{\theta_v}\left(\overline{w'\theta'_v}\right)} - \boxed{\overline{u'w'}\frac{\partial U}{\partial z}} - \boxed{\frac{\partial\left(\overline{w'e}\right)}{\partial z}} - \frac{1}{\rho}\frac{\partial\left(\overline{w'p'}\right)}{\partial z} - \boxed{\varepsilon}$$

tendency — buoyancy — shear — TKE turbulent transport — pressure correlation term — dissipation

(Advection not included)

Is this term missing in the WRF TKE budget? The closure is not achieved (more evident in the anabatic stage).

FOOTPRINT ESTIMATION: Area that contributes to the measured flux at a certain location, estimated from a distribution function. We use a Lagrangian Stochastic Dispersion Model (LSDM), [6]. The cross-wind integrated footprint:

$$F^y(x,z_m) = \frac{1}{k^2x^2}Dz_u^P|L|^{1-P}e^{-\frac{Dz_u^P|L|^{1-P}}{k^2x}},$$

where z_u is a length scale, z_m the effective height of the sensors, D and P similarity constants, L the Obukhov length and k the Von Kármán constant. Extending it to 2D adding the contribution of lateral dispersión [7]:

$$f(x,y,z_m) = D_y(x,y)\cdot F^y(x,z_m) = \frac{1}{\sqrt{2\pi}\sigma_y}\cdot e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2}\cdot F^y(x,z_m),$$

with σ_y being the standard deviation of the lateral-wind fluctuations.

Katabatic direction: 337° (NW)

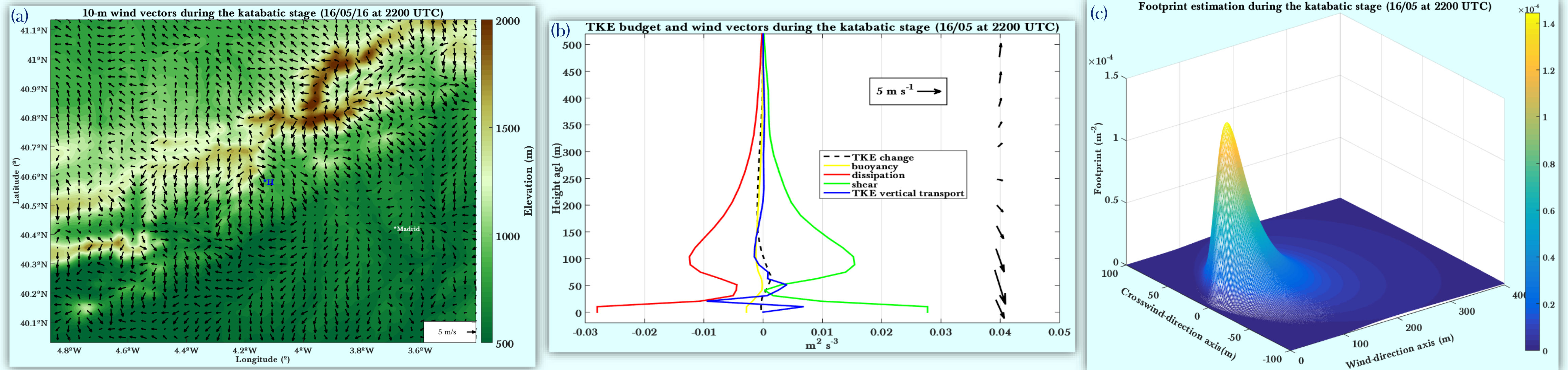


Figure 6. (a) Simulated 10-m wind vectors and topography of the model in the inner domain on 16/05 at 2200 (katabatic stage). The position of *La Herrería* is pointed by a blue 'H'. (b) Simulated vertical TKE budget and wind profile in *La Herrería.* (c) Simulated footprint in the measuring point (0,0). The employed simulation in (a), (b) and (c) is mynn2_mm5*, since it orivdes the turbulence-budget terms.

During the katabatic stage, the TKE production is mainly due to wind shear, whereas the main contributor in the anabatic stage is the turbulent transport.

Greatest difficulty to satisfy the flux-fetch requirement (see Figure 3) at the katabatic stage (greater footprint area) than during the anabatic stage.

Anabatic direction: 177° (S)

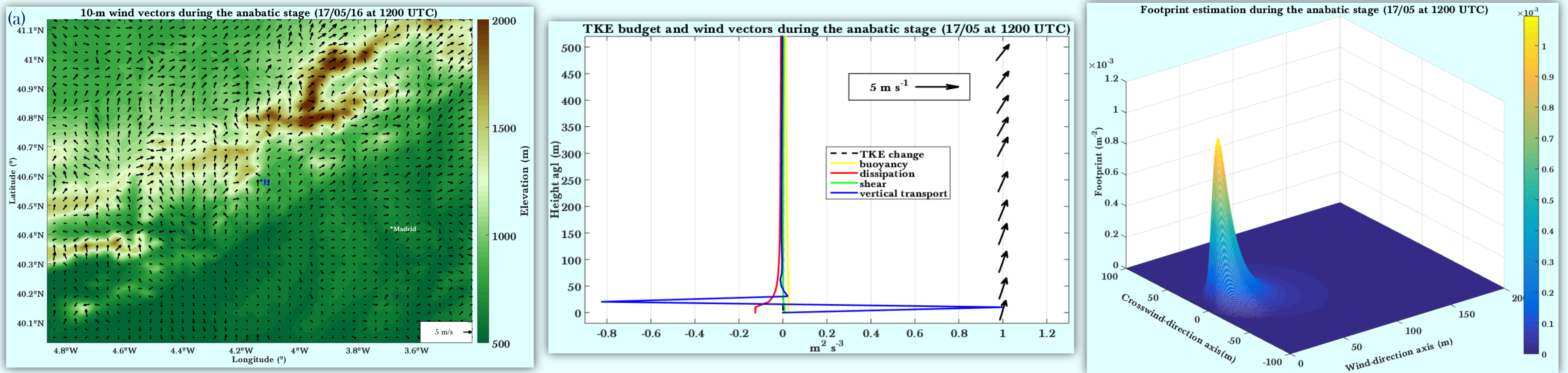


Figure 7. The same as in Figure 6, but for the anabatic stage.

5. CONCLUSIONS & FUTURE PERSPECTIVES

The WRF model reproduces the downslope and upslope winds over *La Herrería* site in the four simulations, even though the use of the *topowind* option makes it more difficult to identify both stages.

The TKE closure is not achieved, which suggests that the pressure-correlation term is lacking in the model output.

The surface area corresponding to the simulated footprint is significantly greater during the katabatic stage, indicating a greater difficulty to satisfy the flux-fetch requirements than in the anabatic stage.

FUTURE PERSPECTIVES
- Interaction between slope flows and turbulence (micrometeorological measurements shortly available at *La Herrería* site).
- CO_2 and energy-budget studies.
- Comparison of the observed and simulated mesoscale circulations: evaluation of the WRF model.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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