Mountain Breezes at Three Different Sites: Salt Lake Valley, The Pyrenees and Guadarrama Mountain Range

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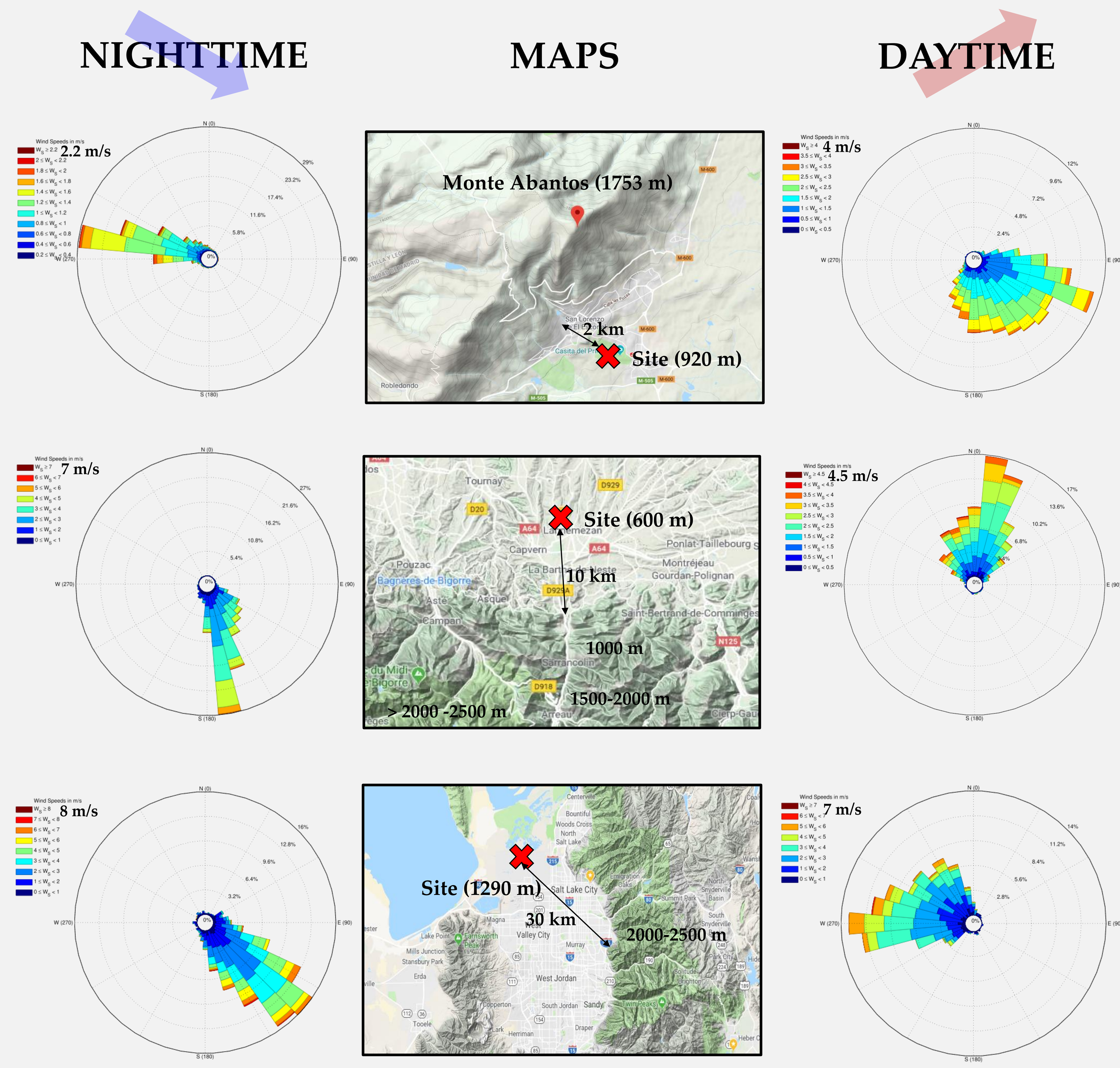
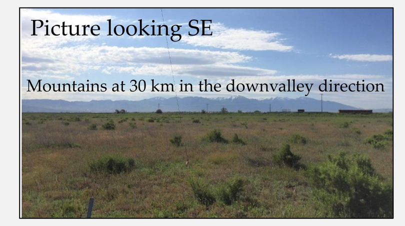
Obj. 1. Characterization of mountain breezes

PRELIMINARY RESULTS!



GUADARRAMA MOUNTAINS
365 days analysed
177 nighttime events (pure katabatics)
136 daytime events (anabatic + upbasin winds)

PYRENEES
365 days analysed
112 nighttime events (mountain-plain / influenced by downvalley)
136 daytime events (plain-mountain)



SALT LAKE VALLEY
210 days analysed
36 nighttime events (downvalley)
38 daytime events (upvalley + lake breeze!)

Figure 1. Map (from Google Maps/Google Earth © 2018) of the areas of study: La Herrería site (Guadarrama mountains) on top, Lannemezan site (Pyrenees) in the middle and Salt Lake Valley site (Rocky Mountains) at the bottom. The location of each tower is indicated with red X. Windroses include all the detected nighttime (left) and daytime (right) flows. Information about the detected events is shown at the right. All the thermally driven flows have been detected automatically with a detection algorithm based on appropriate synoptic conditions (fair weather) for mountain breezes formation and on appropriate wind directions for day and night flows (based on criteria in Arrillaga et al. 2018 QJRMS) . Note the greater complexity in the SLC site, also influenced by the lake breezes.

Nighttime flows onset time

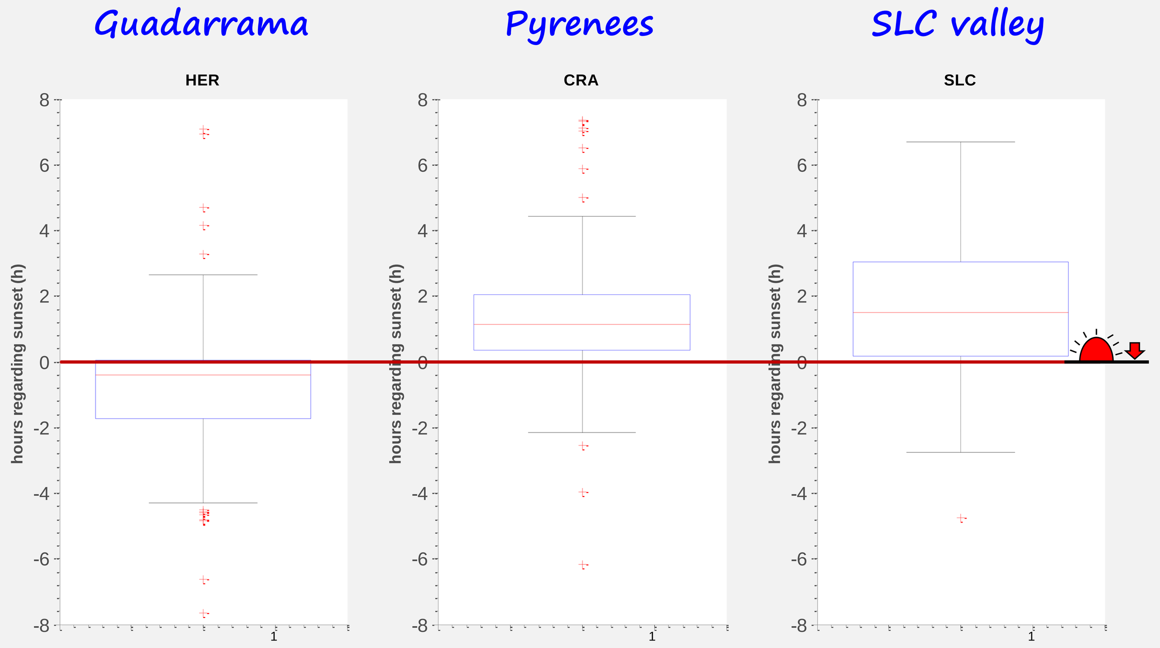


Figure 2. Data distribution boxplots for nighttime breezes onset time regarding sunset, indicated with red line. (e.g. +1 means that the breeze arrive 1 hour after the sunset). All the detected events indicated in Fig. 1 have been used. Note the sooner formation of pure katabatic flows in Guadarrama site due to the proximity of the mountain influencing the site in comparison with the other sites, situated far away from the mountain ranges.

Nighttime flows mean wind speed

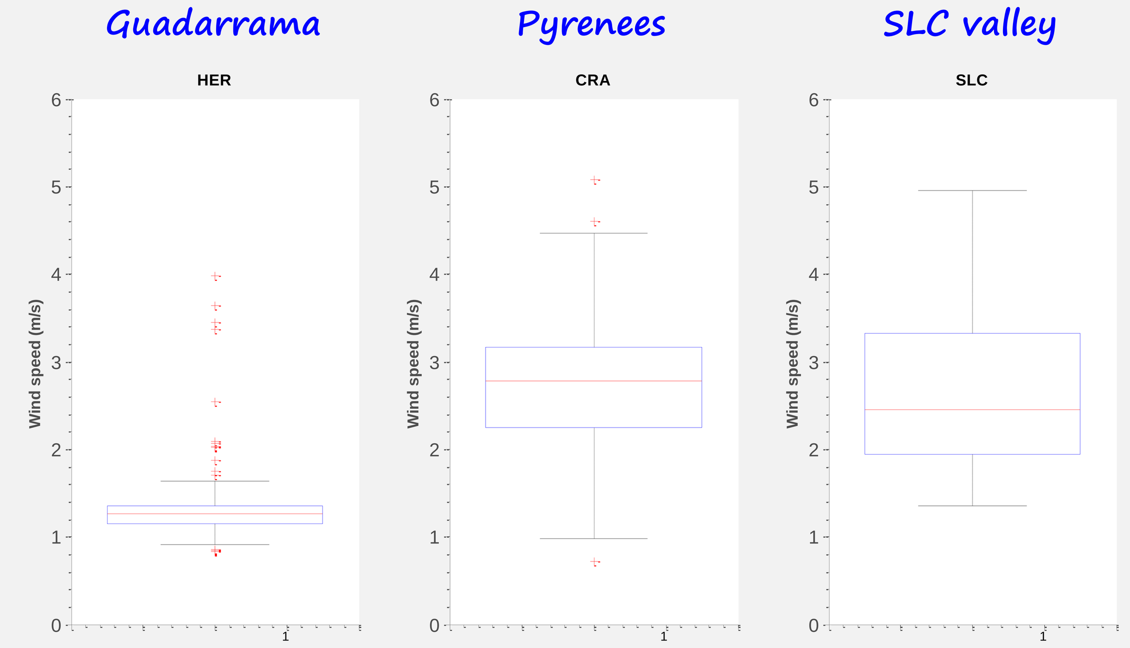


Figure 3. Data distribution boxplots for nighttime-breezes mean wind speed at 10 m* (from observational towers). All the detected events indicated in Fig. 1 have been used. Note the smaller values at the Guadarrama site, which is in fact the site closer to the mountain.

*Wind speed at the Pyrenees site measured at 15 m (slightly smaller values will be then expected at 10 m).

Obj. 2. Mountain breezes impacts in CO_2*

* Analysis shown only for nighttime flows

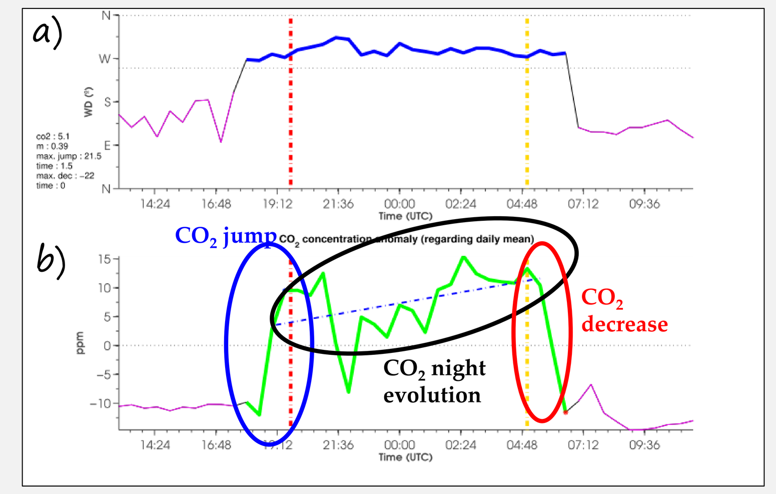


Figure 4. Example of downslope (katabatic) event in Guadarrama site and its effect in CO_2. a) Wind direction measured at 10 m and b) CO_2 concentration measured by IRGASON installed at 8 m.

Three different stages during the katabatic event are identified:

- **CO_2 jump:** Is it related to the katabatic onset (advection)? Which are the variables that control the jump?
- **CO_2 night evolution:** Can we observe a seasonal variability? Are the oscillations controlled by turbulence?
- **CO_2 decrease:** Is the speed of the CO_2 decrease related to the speed of the morning transition (PBL growth)?

This CO_2 evolution is affected by different mechanisms: PBL dynamics and height, surface turbulence and stability, advection, plant activity, "soil" respiration and possible mixing with air from above.

CO_2 jump

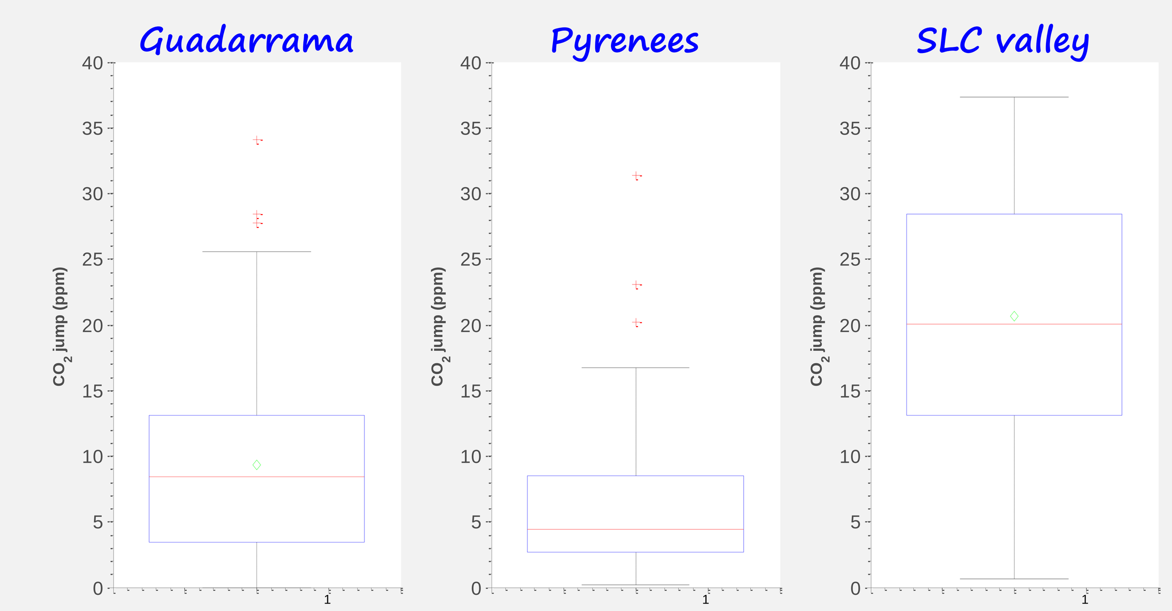


Figure 5. Data distribution of the CO_2 jump observed during the evening transition for all days with nighttime mountain breezes. Note the considerably larger values at the SLC site (larger CO_2 diurnal cycle in this site due to the drastic change of wind conditions between nighttime (air crossing city) and daytime (air from the lake)) flows (see maps). The time of the CO_2 jump occurs approximately at the same time of the onset of the nighttime flow, but in some cases both phenomena are also observed with a time delay, indicating that advection is not the main factor influencing the jump.

CO_2 night evolution (slope)

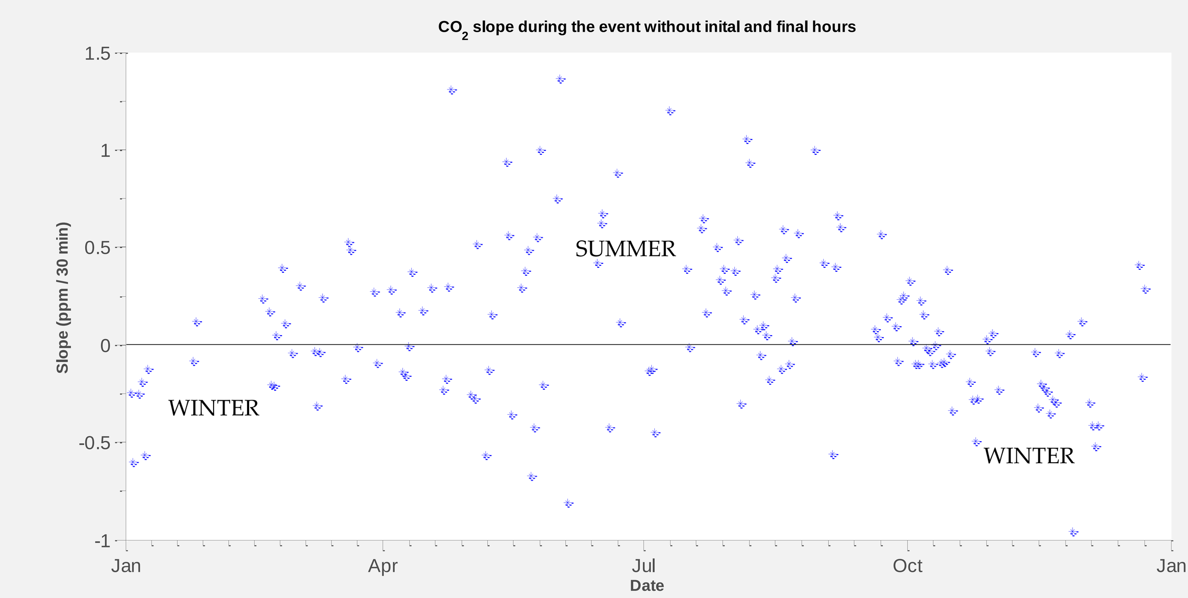


Figure 6. CO_2 night-evolution slope (indicated in black in Figure 4) during the whole year (2017) at Guadarrama site (each point represents the slope found during each detected katabatic event). Note the tendency of finding more positive values during summer than in winter, possible related to a higher plant and soil bacteria activity during this season, producing a continuous increase in CO_2 along the night.

CO_2 & wind direction (advection effects)

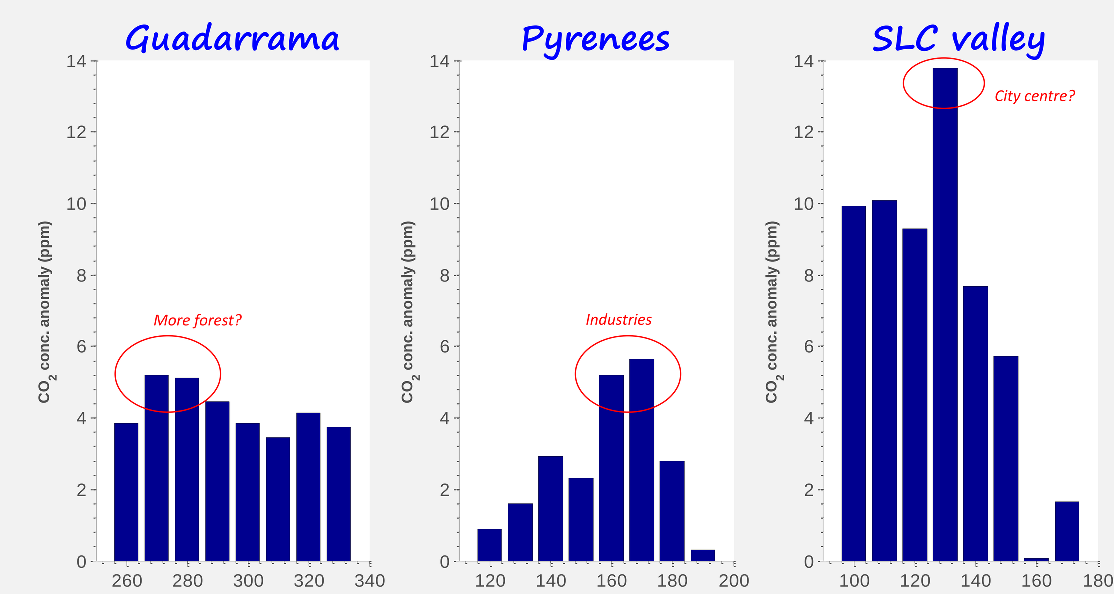


Figure 7. CO_2 concentration (minus daily mean) associated to different wind directions (x-axis) during nighttime flows. Some wind directions are associated to higher CO_2 concentrations, indicating a possible advection effect from these directions. However a deeper analysis of this fact needs to be done to confirm these attributions. In fact, also the turbulent conditions can differ between the different directions, distortioning the conclusions.

CO_2 & turbulence (TKE)

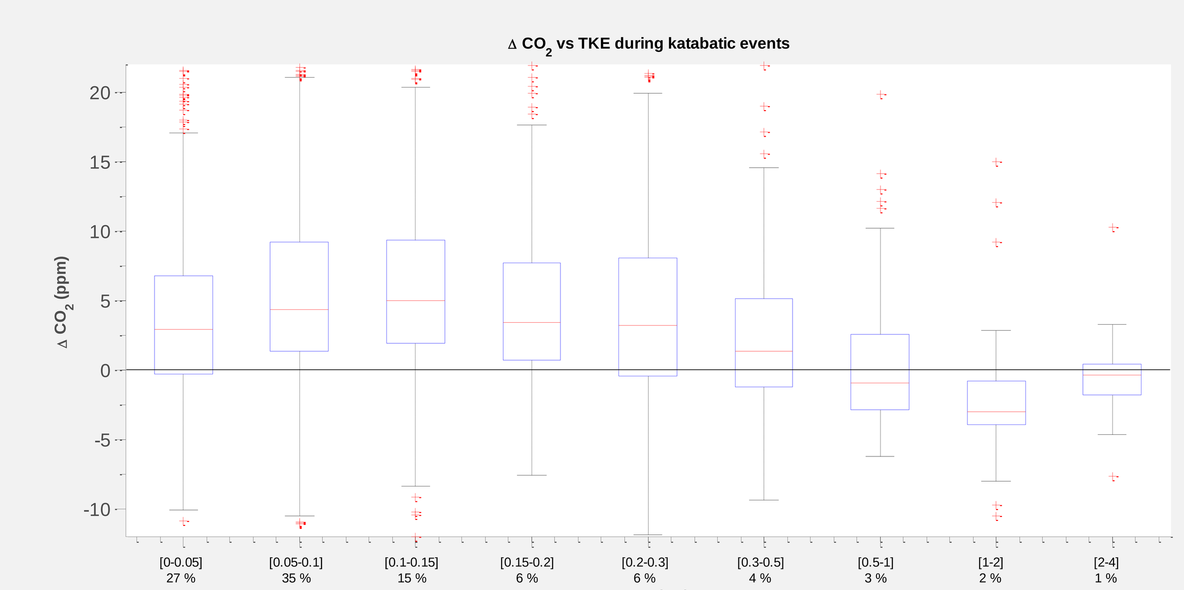


Figure 8. CO_2 concentration (minus daily mean) associated to different turbulent kinetic energy values (x-axis) during katabatic events in Guadarrama site. Note the tendency to lower concentrations of CO_2 with increasing surface turbulence. Note also the slightly lower CO_2 values for TKE < 0.05 m^2/s^2, possibly related to a higher concentration in the layers below the height of the sensor (8 meters).

CONCLUSIONS

OBJECTIVE 1

- Mountain breezes have been detected and characterized at 3 sites.
- Differences are due to the type of phenomena (katabatic, mountain-plain, valley flows), distance to the mountains, tower location…
- The SLC sites presents more complexity than the other two sites.

OBJECTIVE 2

- CO_2 concentration seems modulated by:
  - PBL dynamics, "mixing" height and turbulence
  - Some influence of wind direction (advection)…
  - Plant activity (affecting slope night evolution)
- Undetermined effects (not yet):
  - Mixing from "above" in SBL (Gravity waves? Residual eddies?).
  - "Soil" respiration??

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