Observational characterization of mountain breezes and their impacts on CO₂ mixing ratios


P2OA
Matinée scientifique
14 November 2018
Toulouse
Observational characterization of mountain breezes and their impacts on CO$_2$ mixing ratios

C. Román-Cascón$^1$,$^2$, C. Yagüe$^1$, J.A. Arrillaga$^1$, M. Lothon$^2$, E. Pardyjak$^3$, F. Lohou$^2$, RM. Inclán$^4$, M. Sastre$^1$, G. Maqueda$^1$, S. Derrien$^2$, Y. Meyerfeld$^2$, C. Hang$^3$, P. Campargue-Rodríguez$^2$, I. Turki$^2$
Project context and objectives

ATMOUNT II project

- Guadarrama Mountains (Herrería) (Spain)
- Pyrenees (France)
- Salt Lake Valley (US)

• **Obj. 1:** Characterization of mountain breezes
  - Guadarrama Mountains (Herrería) (Spain)
  - Pyrenees (France)
  - Salt Lake Valley (US)

• **Obj. 2:** Impacts of mountain breezes in CO$_2$ (micro-mesoscale interactions)
Mountain breezes detection

DETECTION ALGORITHM*

- **LARGE SCALE**: Synoptic conditions - NCEP: u, v, T, RH
  
  - Filter 1: Wind at 700 hPa < 9-10 m/s → 365 days analysed
  - Filter 2: Fronts passage; \( \Delta T_{700 \text{ hPa}} \) > -1.45 K/6 hours → 179 days pass Filter 1
  - Filter 3: Rainfall < 0.2 mm/day → 168 days pass Filter 1 and 2

  → 135 days pass Filter 1, 2 and 3
Mountain breezes detection

DETECTION ALGORITHM*

- **LARGE SCALE**: Synoptic conditions - NCEP: u, v, T, RH
  - Filter 1: Wind at 700 hPa < 9-10 m/s
  - Filter 2: Fronts passage; Δθ, 700 hPa > -1.45 K/6 hours
  - Filter 3: Rainfall < 0.2 mm/day
  → 365 days analysed
  → 179 days pass Filter 1
  → 168 days pass Filter 1 and 2
  → 135 days pass Filter 1, 2 and 3

- **SMALL SCALE**: Local conditions - Wind Direction (WD) from tower
  - Ranges of WD for down (nighttime) / up (daytime) events
  - WD persistence (80% of event) in the appropriate range
  - Minimum duration of events (3 hours min)
  → 112 nighttime & 56 daytime events

* Based on criteria in Arrillaga et al. 2018 (QJRMS)

CENTRE DE RECHERCHES ATMOSPHÉRIQUES (CRA, Pyrenees) (2017 Example)
CRA (Pyrenees)
CRA (Pyrenees)

Site (600 m)

>) 2000 - 2500 m

1500 - 2000 m

Pic du Midi de Bigorre, 2877 m

From Google Maps
Mountain breezes events (examples)

**Nighttime event**

- Nighttime event example
- Daytime event example
- Nighttime events mean + sd
- Daytime events mean + sd
- SH sign change (+ to -) (- to +)

**Daytime event**

- WD range upslope flow

Site (600 m)
Mountain breezes events (examples)

**Nighttime event**

21/8/2017 - Wind direction / events variability (shadows)

- Wind direction: N, W, S, E
- Time (UTC): 14, 17, 20, 23, 02, 05, 08, 11, 14
- WD range: downslope flow

**Daytime event**

9/4/2017 - Wind direction / events variability (shadows)

- Wind direction: N, W, S, E
- Time (UTC): 04, 07, 10, 13, 16, 19
- WD range: upslope flow

CRA example

**Mountain breezes statistics**

- Timing / duration of events
- Wind speed & Wind direction (mean and variability)
- Impacts on greenhouse gases concentration
CRA (Pyrenees)

**Nighttime**

**Daytime**

**EVENTS NUMBERS:**

- 365 days analysed
- 112 nighttime
- 56 daytime
La Herrería (Guadarrama) - HER

Guadarrama Mountains

From Google Maps
La Herrería (Guadarrama) - HER

EVENTS NUMBERS:
365 days analysed
177 nighttime
136 daytime
Salt Lake Valley (Rocky Mountains) - SLV

From Google Maps
Salt Lake Valley (Rocky Mountains) - SLV

Site (1300 m)

2000 m

2500 m

Mountains at 30 km

Photo direction

From Google Maps
Salt Lake Valley (Rocky Mountains) - SLV

**Nighttime**

- 5 m/s
- 17% winds
- Site (1300 m)
- Mountains at 30 km
- 2000 – 2500 m

**Daytime**

- 5 m/s
- 14% winds
- Site (1300 m)
- Mountains at 30 km
- 2000 – 2500 m

**EVENTS NUMBERS:**
- 201 days analysed
- 30 nighttime
- 31 daytime
Mountain breezes arrival time (regarding sunset)

**Nighttime events**

- **Guadarrama**
  - Site closer to the mountain slope.
  - Sooner arrival of “katabatic” winds

- **Pyrenees**

- **SLC valley**
  - Mountain-plain and valley winds (larger scale)
  - Later arrival

**Daytime events**

**Number of events**

<table>
<thead>
<tr>
<th>Hours</th>
<th>No. of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4</td>
<td>0</td>
</tr>
<tr>
<td>-2</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

SH change from + to -
Mountain breezes arrival time (regarding sunset)

**Nighttime events**

**Daytime events**

- **Pyrenees**
- **SLC valley**
- **Guadarrama**

Number of events

- SH change from + to -
- SH change from - to +

Similar results for daytime breezes

Large variability at SLV due to interaction with lake breezes
Objective 2. CO₂ & mountain breezes

CO₂ diurnal cycle. What is the influence of the mountain breezes?

CO₂ evolution:
- Plant activity
- “Soil” respiration
- PBL dynamics (height)*
- Degree of turbulence*
- Advection*
- Mixing from “above”*

* Potentially influenced by mountain breezes

DAYTIME → Less CO₂ (photosynthesis)
NIGHTTIME → More CO₂ (respiration)
Objective 2. CO$_2$ & mountain breezes

**CO$_2$ jump**
Katabatic onset?

**CO$_2$ night evolution (slope)**
TKE?

**CO$_2$ decrease**
Anabatic onset?
Mean CO$_2$ concentration* during events

MEAN CO$_2$ during the events??
Mean CO$_2$ concentration* during events

**Nighttime events**

**Daytime events**

* Minus daily mean (anomaly)

Mean CO$_2$ concentration (daily) anomaly

[Graph showing CO$_2$ anomaly over months for different locations: HER, CRA, SLV.]

**MEAN CO$_2$ during the events??**

**POSITIVE VALUES**
Mean CO$_2$ concentration* during events

**Nighttime events**

**Daytime events**

MEAN CO$_2$ during the events??

NEGATIVE VALUES

POSITIVE VALUES
Mean CO₂ concentration anomaly for different TKE values

GUADARRAMA 10 m
Max. CO₂ concentration for TKE ~ 0.1-0.15 m²/s²

* Minus daily mean (anomaly)
Mean CO₂ concentration anomaly for different TKE values during nighttime events.

- **GUADARRAMA 10 m**: Max. CO₂ concentration for TKE ~ 0.1-0.15 m²/s².
- **PYRENEES 30 m**: Max. CO₂ concentration for TKE ~ 0.3-0.5 m²/s².

*Minus daily mean (anomaly)*
Mean CO$_2$ concentration anomaly for different TKE values

- **SLC 10 m**: Max. CO$_2$ concentration for TKE $\sim$ 0.025-0.05 m$^2$/s$^2$
- **GUADARRAMA 10 m**: Max. CO$_2$ concentration for TKE $\sim$ 0.1-0.15 m$^2$/s$^2$
- **PYRENEES 30 m**: Max. CO$_2$ concentration for TKE $\sim$ 0.3-0.5 m$^2$/s$^2$
Mean CO$_2$ concentration anomaly for different TKE values

**CO$_2$* vs TKE during nighttime events**

* Minus daily mean (anomaly)

Different dataset (BLLAST 2011)

Work of P. Campargue-Rodriguez and I. Turki (M1 students)

Different TKE ranges (m$^2$/s$^2$)

CO$_2$ daily anomaly (ppm)

PYRENEES 2 m
Max. CO$_2$ concentration for low TKE

PYRENEES 30 m
Max. CO$_2$ concentration for high TKE
Nighttime events

$CO_2^*$ concentration for different WD

- Guadarrama
- Pyrenees
- SLC valley

* Minus daily mean (anomaly)
Conclusions

- Different features of MOUNTAIN BREEZES due to:
  - Type of phenomena (katabatic, mountain-plain, valley-channelled flows)
  - Distance to the mountains, tower location...

- CO$_2$ modulated by:
  - PBL transitions: stable $\leftrightarrow$ convective
  - Turbulence (especially during nighttime)
  - Wind direction (advection) in very heterogeneous sites (SLC)

  and...

- Mixing from “above” in SBL (Gravity waves? Residual eddies?)
- Soil respiration??
- Plants activity??
Merci!