Analyzing features and impacts of mountain breezes at three different mountainous sites

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EMS
04 September 2018
Budapest
ATMOUNT II project

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

- Obj. 1: Characterization of mountain breezes
- Obj. 2: Impacts of mountain breezes in CO₂ (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  
  $\rightarrow$ 201 days pass Filter 1

- Filter 2: Fronts passage; $\Delta \theta_e$  
  $> -1.45$ K/6 hours  
  $\rightarrow$ 193 days pass Filter 1 and 2

- Filter 3: Rainfall  
  $< 0.2$ mm/day  
  $\rightarrow$ 188 days pass Filter 1, 2 and 3

LA HERRERIA (Guadarrama Mountains)  
(2017 Example)

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

DETECTION ALGORITHM*

- **LARGE SCALE**: Synoptic conditions - NCEP: u, v, T, RH

  - Filter 1: Wind at 700 hPa < 9-10 m/s → 201 days pass Filter 1
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  - Filter 3: Rainfall < 0.2 mm/day → 188 days pass Filter 1, 2 and 3

  → 365 days analysed

- **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 → 177 nighttime & 136 daytime events
  - Minimum duration of events (3 hours min)

LA HERRERIA (Guadarrama Mountains) (2017 Example)

* Based on criteria in Arrillaga et al. 2018 (QJRMS)
Mountain breezes events (examples)

**Nighttime event**

**Daytime event**

Guadarrama example

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**13/8/2017 - Wind direction and speed**

- **wd**
- **Nighttime event**
- **Daytime event**
- **ws**
- SH sign change (+ to -) (- to +)
- Sunset / Sunrise
Mountain breezes events (examples)

**Nighttime event**

**Daytime event**

With all events…

Mountain breezes statistics

Timing / duration of events.

Wind speed & Wind direction (mean and variability).

Impacts on greenhouse gases concentration, fluxes, turbulence and stability…
La Herrería (Guadarrama) - HER

Guadarrama Mountains
Monte Abantos
(1753 m)

Site
(920 m)

Peñalara, 2428 m

Madrid, 40 km

La Herrería (Guadarrama) - HER
La Herrería (Guadarrama) - HER

**Downslope**

Wind Speeds in m/s

\[ W_s \geq 2.2 \]
\[ 2 \leq W_s < 2.2 \]
\[ 1.8 \leq W_s < 2 \]
\[ 1.6 \leq W_s < 1.8 \]
\[ 1.4 \leq W_s < 1.6 \]
\[ 1.2 \leq W_s < 1.4 \]
\[ 1 \leq W_s < 1.2 \]
\[ 0.8 \leq W_s < 1 \]
\[ 0.6 \leq W_s < 0.8 \]
\[ 0.4 \leq W_s < 0.6 \]
\[ 0.2 \leq W_s < 0.4 \]

**Upslope**

Wind Speeds in m/s

\[ W_s \geq 2.2 \]
\[ 2 \leq W_s < 2.2 \]
\[ 1.8 \leq W_s < 2 \]
\[ 1.6 \leq W_s < 1.8 \]
\[ 1.4 \leq W_s < 1.6 \]
\[ 1.2 \leq W_s < 1.4 \]
\[ 1 \leq W_s < 1.2 \]
\[ 0.8 \leq W_s < 1 \]
\[ 0.6 \leq W_s < 0.8 \]
\[ 0.4 \leq W_s < 0.6 \]
\[ 0.2 \leq W_s < 0.4 \]

**EVENTS NUMBERS:**

365 days analysed
177 downslope
136 upslope

Mountains at 2-3 km

2.2 m/s

La Herrería (Guadarrama) - HER
CRA (Pyrenees)
CRA (Pyrenees)

- Site (600 m)
- Photo direction
- Pic du Midi de Bigorre, 2877 m
- 1000 m
- 1500-2000 m
- > 2000 -2500 m
Wind Speeds in m/s

- $W_s \geq 5$
- $4 \leq W_s < 5$
- $3 \leq W_s < 4$
- $2 \leq W_s < 3$
- $1 \leq W_s < 2$
- $0 \leq W_s < 1$

**Downslope**

**Upslope**

**EVENTS NUMBERS:**
- 365 days analysed
- 112 downslope
- 56 upslope
Salt Lake Valley (Rocky Mountains) - SLV
Salt Lake Valley (Rocky Mountains) - SLV

Site (1300 m)

Photo direction

Mountains at 30 km

2000 m

2500 m
EVENTS NUMBERS:
201 days analysed
30 downslope
31 upslope
Mean WIND SPEED

Nighttime events

Daytime events

- Mean
- Median
- Outliers

Guadarrama  Pyrenees  SLC valley

Guadarrama  Pyrenees  SLC valley
Mountain breezes arrival time (regarding sunset)

**Nighttime events**

- Guadarrama
- Pyrenees
- SLC valley

**Daytime events**

- Site closer to the mountain slope.
- Sooner arrival of “katabatic” winds
- Mountain-plain and valley winds (larger scale)
- Later arrival
- SH change from + to -
Mountain breezes arrival time (regarding sunset)

**Nighttime events**

- **Guadarrama**
  - No. events: [Graph showing distribution]
- **Pyrenees**
  - No. events: [Graph showing distribution]
- **SLC valley**
  - No. events: [Graph showing distribution]

**Daytime events**

- **Guadarrama**
  - No. events: [Graph showing distribution]
- **Pyrenees**
  - No. events: [Graph showing distribution]
- **SLC valley**
  - No. events: [Graph showing distribution]

*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. \( \text{CO}_2 \) & mountain breezes

- \( \text{CO}_2 \) diurnal cycle. What is the influence of the mountain breezes?

\[ \text{CO}_2 \text{ evolution} \quad \begin{cases} \text{PBL dynamics*} \\
\text{Degree of turbulence*} \\
\text{Advection*} \\
\text{Mixing from “above”*} \\
\text{Plant activity} \\
\text{“Soil” respiration} \end{cases} \]

* Potentially influenced by mountain breezes
Objective 2. $\text{CO}_2$ & 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 $CO_2$ during the events??

Mean $CO_2$ concentration (daily) anomaly

POSITIVE VALUES
Mean $CO_2$ concentration* during events

**Nighttime events**

**Daytime events**

*Minus daily mean (anomaly)*

**Mean $CO_2$ concentration (daily) anomaly**

**NEGATIVE VALUES**

**POSITIVE VALUES**
$\text{CO}_2$ vs TKE during downslope flows

Mean $\text{CO}_2$ concentration anomaly for different TKE values

GUADARRAMA 10 m
Max. $\text{CO}_2$ concentration for TKE ~ 0.1-0.15 $\text{m}^2/\text{s}^2$

* Minus daily mean (anomaly)
Mean CO₂ concentration anomaly for different TKE values

**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\textsubscript{2} concentration anomaly for different TKE values

SLC 10 m
Max. CO\textsubscript{2} concentration for TKE \sim 0.025-0.05 m\textsuperscript{2}/s\textsuperscript{2}

GUADARRAMA 10 m
Max. CO\textsubscript{2} concentration for TKE \sim 0.1-0.15 m\textsuperscript{2}/s\textsuperscript{2}

PYRENEES 30 m
Max. CO\textsubscript{2} concentration for TKE \sim 0.3-0.5 m\textsuperscript{2}/s\textsuperscript{2}

* Minus daily mean (anomaly)
Downslope flows

$CO_2^*$ concentration for different WD

* Minus daily mean (anomaly)

**HER**

**CRA**

**SLC**

More forest?

Industries?

Airport – City centre?

TRYING TO DETERMINE THE ADVECTION EFFECT...
Conclusions

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

- CO₂ modulated by:
  - PBL transitions: stable ↔ convective
  - Turbulence
  - Wind direction (advection) in very heterogeneous sites (SLC)

and…

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

Mountain breezes influence CO₂ concentrations
Thanks!

Picture taken close to La Herrería site, looking North. San Lorenzo del Escorial (Madrid, Spain)