KASCADE: Stable Boundary Layer Characterization in an Orographic Complex Region

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Acknowledgements:

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LPCA: P. Augustin, M. Fourmentin

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Session Stable Boundary Layers 3: June 10, 2014
Motivation

→ Certain facilities at Cadarache could accidentally emit pollutants in the SBL.
→ Stable Boundary Layer (SBL) is one of the most penalizing conditions for pollutant release in the atmosphere.
→ Clear skies and calm winds in the Provence occurs frequently & throughout the year and is influenced by local relief modifying local stability-related flows
→ The Provence is one of most densely populated parts of France and has an active agricultural area

KASCADE-campaign: KAtabatic winds and Stability over CAdarache for Dispersion of Effluents

Phd-Thesis:
“Dispersion of pollutants in stable boundary layer conditions in the Durance middle valley”
Physical geography of Provence

- Large variety of orography and land use
- Influences of different synoptical and local meteorological events
  - Several field campaigns, except for *SBL over complex terrain*

**Map**

- *Rhône Valley*
- *Mistral*
- *Durance Valley*
- *Southern Alps*
- *Cadarache*
- *Sea breeze (summer months)*
- *Local slope and valley winds during stable conditions in Durance middle valley: KASCADE 2013*
- *Precipitation events*
- *Mediterranean Sea*
At the junction of 2 valleys

- Shallow valleys
- Less than moderate slope
- Both impact differently on local wind field and thus dispersion
Measurement locations during KASCADE

SODAR (0 – 500m): U and $U_{\text{dir}}$, turbulent characteristics
Characteristics wind (long-term: Nov. 2012 - ongoing!)
Outside Cadarache Valley

Tethered Balloon (0 – 300m): Profiles U, $U_{\text{dir}}$, T, RH
Determination SBL-height, shear
Modelling (validation)
Inside Cadarache Valley

30m flux tower:
3 sonic anemometers (H, LvE, $\tau$)
2 net radiometers (LW*, SW*)
2 thermohygrometers (T, RH)
Purpose:
Characterize SBL (dT, rad)
Modelling (input parameters and validation data)
Inside Cadarache Valley

Radiosoundings (<5km):
Profiles U, $U_{\text{dir}}$, T, RH
Determination synoptic situation
Modelling
Radiation divergence

- 2 net radiometers at $z_1=1.20$ m and $z_2=20.0$ m
- Relative calibration in Lannemezan, focused on nighttime.
- Corrections on calibration coefficient and body temperature for CNR1.

Median of 31 dry nights between 09/01 (15 hrs) and 17/03 (12 hrs).

**Tendency:**
Maximum cooling by LHR around sunset, cooling gradually decreases, consistent till after sunrise.

After sunrise Turbulent Heating Rate takes over transport of heat.

Shortly after sunset: 40% of cooling explained by LHR.
Missing terms:
- Turbulence, advection, subsidence

### Evolution SBL:

\[
\frac{\Delta \theta}{\Delta t} = 3600 \cdot \left(-\frac{\Delta w \theta}{\Delta z} - \frac{1}{\rho C_p} \frac{\Delta LW^*}{\Delta z} \right) \frac{K}{h}
\]

<table>
<thead>
<tr>
<th>Errors</th>
<th>$\delta \Delta LW$ [W m$^{-2}$]</th>
<th>$\delta$ LHR [$^\circ$C h$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.94</td>
<td>0.15</td>
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<tr>
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<td>1.36</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Kascade Heating rates 31 nights median

- $-\sigma$ +$\sigma$
A night during KASCADE

**Wind direction:**
- Before sunset westerly (up-valley) flow
- At sunset flow turns to down valley wind, starting from the surface
- Down valley flow remains until sunrise...
- Cadarache valley katabatic wind → drainage flow
- Durance valley wind → channeled?

**Temperature behavior:**
Typically a stable layer forms 1 – 1.5 hr before sunset.
SBL-formation and local winds

Synoptic NW-flow (> 1km)

IOP-15
Sunset 1710 UTC
Sunrise 0632 UTC

- SBL-height = 225m
- SBL-strength =~6.5°C
- Stack of layers:
  - SBL<sub>CV</sub> < 60m
  - SBL<sub>DV</sub>

Flow characteristics

<table>
<thead>
<tr>
<th></th>
<th>Cadarache Valley</th>
<th>Durance Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow depth</td>
<td>80-100m</td>
<td>250m</td>
</tr>
<tr>
<td>Jet height</td>
<td>40m</td>
<td>175m</td>
</tr>
<tr>
<td>Max wind speed</td>
<td>2 m/s</td>
<td>6 m/s</td>
</tr>
</tbody>
</table>
SBL-formation and local winds

Sunset 17:10 UTC
Sunrise 06:32 UTC

IOP-15

- SBL-height = 225m
- SBL-strength =~6.5°C
- Stack of layers:
  - SBL\textsubscript{CV} < 60m
  - SBL\textsubscript{DV}

Synoptic NW-flow (> 1km)

05 UTC

Cadarache Valley (135°)

- NW-flow (> 1km)

- 30°
- 135°

- CV-flow
- DV-flow

- 100m
SBL-formation and local winds

IOP-12
Sunset 1702 UTC
Sunrise 0640 UTC

0630 UTC

- 100m – 500m height: Flow into CV (no blocking hill)
- CV drainage flow is formed
- CV-flow reaches height of 50m (instead of >80m)
- Height of CV-flow important for dispersion

- SBL-height = 120m
- SBL-strength = 7.5°C
Summary / conclusions / prospects

KASCADE-dataset...

... 1\textsuperscript{st} SBL field-experiment in South-Eastern France over complex terrain

... shows ability to capture radiation divergence

... reveals the complex wind pattern during SBL-conditions over Cadarache:

- Stack of stable & neutral layers are observed, whose interaction result in complex wind patterns which determine pollutant dispersion
- Results in 2 different stability related flow types
  - Drainage flow: Cadarache Valley wind; independent of above-valley flow
  - Combination of drainage/LLJ/channeled flow? Durance Valley wind dependent on above-valley flow direction
    - Governing mechanisms for DV-wind under investigation

... will serve as validation for high resolution numerical modeling (WRF)

... extend 1D- analysis to 3D-analysis:

\[
\frac{\partial \tilde{\Theta}}{\partial t} = - \frac{\partial \tilde{w} \tilde{\Theta}}{\partial z} - w \frac{\partial L W^*}{\partial z} - \tilde{U}_j \frac{\partial \tilde{\Theta}}{\partial x_j}
\]

(Combination of observations & modeling)

... will be open access by the end of 2015
Merci pour votre attention
Questions...?

More information

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But my name is Gert-Jan...
## IOP- Outlook

### Continuous Observation Period (COP): 2012/12/12 – 2013/03/19

### Intensive Observation Periods: 2013/01/14 – 2013/03/02

7 operational weeks for IOPs:

- 23 IOPs have been conducted
- 16 IOPs have TB-experiments with SBL-development

### 12 – 12 UTC

<table>
<thead>
<tr>
<th>Week#</th>
<th>date</th>
<th>IOP#</th>
<th>General conditions</th>
<th>5/8</th>
<th>CA</th>
<th>EF</th>
<th>PP</th>
<th>SBL</th>
<th>tbl</th>
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<tbody>
<tr>
<td>3</td>
<td>14to15/01</td>
<td>1</td>
<td>---</td>
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<tr>
<td>4</td>
<td>21to22/01</td>
<td>2</td>
<td>--- Mistral</td>
<td>---</td>
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<tr>
<td>22to23/01</td>
<td>3</td>
<td>Clear sky &lt;18UTC</td>
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<td>rain</td>
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<tr>
<td>23to24/01</td>
<td>4</td>
<td>Cloudy to CS/CW</td>
<td>Clear sky; SBL</td>
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<tr>
<td>24to25/01</td>
<td>5</td>
<td>Clear sky. SBL develops</td>
<td>Clear sky; SBL</td>
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<tr>
<td>5</td>
<td>28to29/01</td>
<td>6</td>
<td>--- Mistral d.a.</td>
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<tr>
<td>29to30/01</td>
<td>7</td>
<td>Windy</td>
<td>Clear sky; SBL</td>
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<tr>
<td>30to31/01</td>
<td>8</td>
<td>PP: windy start</td>
<td>---</td>
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<tr>
<td>6</td>
<td>07to08/02</td>
<td>9</td>
<td>--- Mistral</td>
<td>Clear sky; SBL</td>
<td></td>
<td></td>
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<tr>
<td>08to09/02</td>
<td>10</td>
<td>Turbulent cond</td>
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<tr>
<td>7</td>
<td>11to12/02</td>
<td>11</td>
<td>--- Rain</td>
<td>Foggy morning, SBL</td>
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<tr>
<td>12to13/02</td>
<td>12</td>
<td>PP: windy start</td>
<td>Clear sky; SBL</td>
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<tr>
<td>13to14/02</td>
<td>13</td>
<td>PP: windy start + tbl &gt; 200m</td>
<td>Clear sky &amp; tbl</td>
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<tr>
<td>14to15/02</td>
<td>14</td>
<td>Clear sky; SBL</td>
<td>Clear sky; SBL but tbl</td>
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</tr>
<tr>
<td>8</td>
<td>18to19/02</td>
<td>15</td>
<td>CA, 5/8</td>
<td>Clear sky; SBL</td>
<td></td>
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<tr>
<td>19to20/02</td>
<td>16</td>
<td>PP: windy start</td>
<td>Clear sky; some fog</td>
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<tr>
<td>20to21/02</td>
<td>17</td>
<td>Clear sky; tbl</td>
<td>Clear sky; SBL</td>
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<tr>
<td>21to22/02</td>
<td>18</td>
<td>Clear sky; SBL</td>
<td>8/8; RH 100%</td>
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<td>9</td>
<td>25to26/02</td>
<td>19</td>
<td>Snow; Clear sky; SBL; Tmin -8C</td>
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<tr>
<td>26to27/02</td>
<td>20</td>
<td>Clear sky; deep SBL</td>
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<tr>
<td>27to28/02</td>
<td>21</td>
<td>Clear sky; SBL</td>
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<td></td>
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</tr>
<tr>
<td>28to01/03</td>
<td>22</td>
<td>PP:windy start; EF -&gt; rain</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01to02/03</td>
<td>23</td>
<td>Windy start; EF (Saturday)</td>
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</tr>
</tbody>
</table>

### Abbreviations:
- 5/8: Cloud cover
- CA: Calm Atmosphere
- EF: Early Finish
- PP: Postpone of start
- SBL: Stable Boundary Layer
- tbl: Turbulent conditions
Radiation divergence error estimation

**\( \delta \Delta L W \downarrow = 1.36 W m^{-2} \)**

\( \delta \text{LHR} = 0.21 \, ^\circ \text{C} \, \text{h}^{-1} \)

**Total:**

\( \delta \Delta L W = 0.94 W m^{-2} \)

\( \delta \text{LHR} = 0.15 \, ^\circ \text{C} \, \text{h}^{-1} \)

From IC-campaign
Lannemezan
04/2013 – 06/2013
Results – radiation divergence

Evolution SBL:

\[
\frac{\Delta \theta}{\Delta t} = 3600 \left( -\frac{\Delta \bar{w} \theta}{\Delta z} - \frac{1}{\rho C_p} \frac{\Delta L W^*}{\Delta z} \right) \frac{K}{h}
\]

Global Heating Rate (GHR)  Longwave Heating Rate (LHR)

Relative calibration in Lannemezan, focused on nighttime.
Corrections on calibration coefficient and body temperature for CNR1.

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The uncertainty for downward component is twice as large.
LHR upward & downward

Median of 58 dry nights between 09/01 (15 hrs) and 17/03 (12 hrs).

LHR downward shows extra problems for time frame:
- Dew / ice formation early morning → 31 nights retained.

**Tendency:**
Maximum cooling by LHR around sunset, cooling gradually decreases, consistent till after sunrise.

After sunrise Turbulent Heating Rate takes over transport of heat.

Shortly after sunset: 40% of cooling explained by LHR.
Most of uncertainty in around sunrise comes from **downward** part, but median value ~ 0