Observations of Radiation Divergence and Stability-related flows during the Field Experiment KASCADE

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Characterization of Stable Boundary Layer development in a complex region by means of atmospheric measurements

1 Motivation

Cadarache (CAD) is the largest research site of the "Commissariat à l'Energie Atomique et aux Energies Alternatives" (CEA), located in the South-East of France (Fig. 1). The centre comprises several facilities whose operation requires impact assessment because of the emission of pollutants. The stability of the lower atmospheric boundary layer caused by **radiative cooling** at night, combined with the local orography, strongly affects the conditions for the dispersion of potential pollutants. Understanding the complex patterns of **drainage flows** and cold pool build up in the smaller valleys confluent to the Durance River is thus a major issue for refining the models used to assess the sanitary and environmental impact of CAD. KASCADE (**KA**tabatic winds and **S**tability over **CA**darache for **D**ispersion of **E**ffluents) was designed to characterize the local SBL in order to feed future numerical simulations (e.g. WRF) of pollutant dispersion for impact studies.

2 Site Characteristics

Cadarache is situated at the confluence of 2 rivers: the main river Durance and its tributary Le Verdon. **The Cadarache valley** (length: 6km, width: 2km, depth: 100m, hor. slope α: 1.5°, abbrev: VDC) and the lower part of **the Durance middle valley** (l: 47km, w: 5km, d: 200m, α: 0.2°, VDD) are the main valleys of interest. VDC constitutes the greatest part of CAD-centre. VDD narrows from 5km to 200m at Clue de Mirabeau (CDM) where a cold pool could be formed. South of CDM the lower VDD begins and widens to more than 5km.

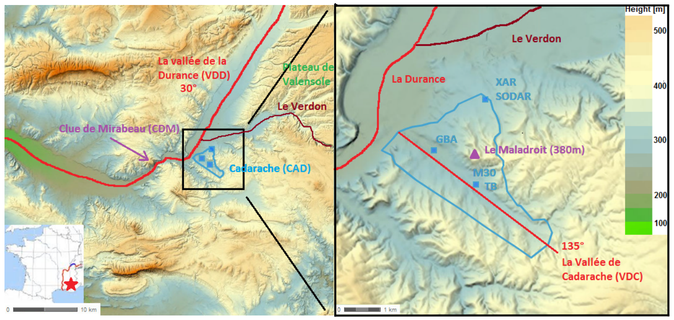

Fig.1 Cadarache (blue) and its surroundings. The "Durance" valley (VDD) and the Cadarache valley (VDC) are highlighted with its valley orientation downwards in degrees from the North. Right: main measurement sites during KASCADE.

3 Experimental Set-Up KASCADE

During the winter of 2013, continuous observations from a **SODAR**, a flux-measurement tower of 30 meter (**M30**) and the meteorological stations Xaria (**XAR**) and La Grande Bastide (**GBA**) at 3 different locations catch the characteristics inside the 2 valleys VDD and VDC (Fig. 1). During 23 IOPs with a focus on near sunset and sunrise transitions in the SBL, Tethered Balloon (**TB**)-profiling with three sondes and radio-soundings complete the dataset.

The work presented here is mainly focused on IOP #15.

KASCADE

Acknowledgements

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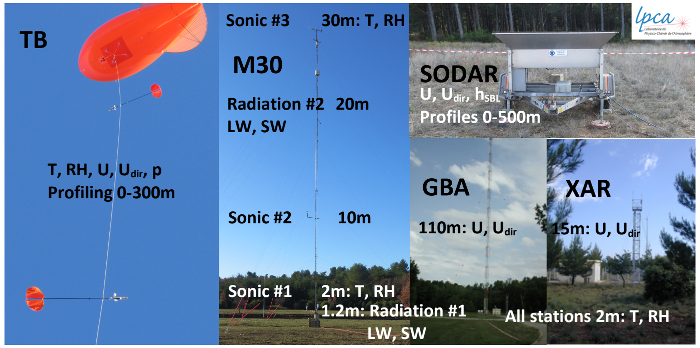

*Fig.2 Sensors used during KASCADE. Height of measurements and/or profiles are given in meters (m). Radiation #1 has been measured on a separated mast at 23m distance from M30. Numbers behind sensors denotes double/triple presence implying availability of **divergence observations***

4 Longwave Heating Rate

For the evolution of the stable boundary layer (SBL) we consider (by neglecting advection and subsidence):

$$\underbrace{\frac{\Delta\theta}{\Delta t}}_{\text{Global Heating Rate (GHR)}} = -\underbrace{\frac{\Delta\overline{w\theta}}{\Delta z}}_{\text{Turbulent Heating Rate (THR)}} - \underbrace{\frac{1}{\rho C_p}\frac{\Delta LW^{\uparrow}}{\Delta z}}_{\text{Longwave Heating Rate (LHR)}}\left[\frac{K}{s}\right]$$

From Steeneveld et al. (2010) and adapted:
GHR: Atmospheric cooling/heating
THR: Approximation of Turbulent Divergence
LHR: Approximation of **Radiation Divergence**

After relative calibration for longwave radiation, the measurement uncertainty δ for $LW^{\uparrow}$ amounts to 0.69 W m^{-2} and equivalent δ of Longwave Heating Rate (LHR) 0.11°C h^{-1}. The measurement set-up is able to measure LHR (Fig. 3a). LHR reaches typically its minimum shortly after sunset and cooling continues until sunrise. Under calm wind conditions, a strong diurnal variation is measured.

Shortly after sunset, **50% of the cooling** observed in the layer 2-30m can be explained by the **radiation divergence** during IOP#15 (Fig. 3b). The difference can be caused by many factors; non-uniform temperature profile, combination of radiation divergence and measurement heights for the estimation, etc.

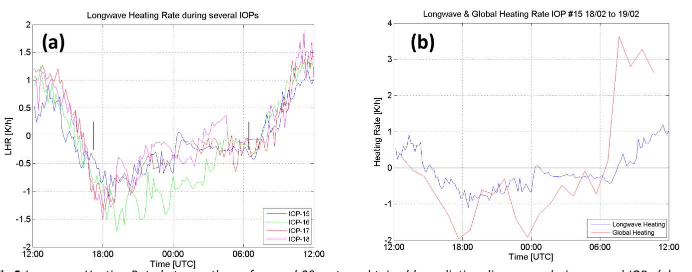

Fig.3 Longwave Heating Rate between the surface and 20 meters obtained by radiation divergence during several IOPs (a) and Global Heating Rate measured by slow measurements (b). The black vertical lines in (a) denote sunrise- and sunset.

5 Stability-related flows

Due to **nocturnal cooling** observed in Section 4 in combination with low synoptic forcing, **local flows** develop. In the measurements we can distinguish **2 different flows** (Fig. 4a) which are attributed to the **VDC** and **VDD** (Fig. 1), respectively.

A TB-profile made between 05h02-05h20 UTC shows the SBL-height of 230m (Fig. 4b). One can distinguish 2 parts: A lower part (SBL_{VDC}) concerning the VDC-valley and an upper part (SBL_{VDD}) which *probably* originates upstream in the VDD. At the transition of these layers a neutral layer exists, which is a result from the wind shear around 100m. This shear layer is a consequence of the sheltering of the VDC by the hill-ridge just north of the TB-site (Fig. 1). An extra neutral layer is possibly found around 200m height and could be associated with turbulent mixing of the VDD-jet with the air mass aloft.

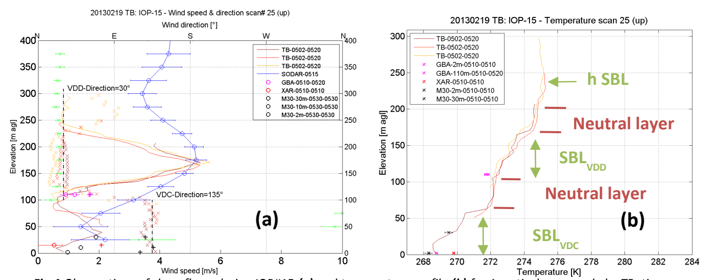

*Fig.4 Observations of slope flows during IOP#15 **(a)** and temperature profile **(b)** for 1 vertical scan made by TB, times are given in the legend and taken at time of passage of a TB-sonde. In (a) circles represent a single measurement, crosses represent wind direction, hence the SODAR wind direction is green. In (b) several layers can be observed concerning stability and having different origins. All station measurements are 10min averages except for the wind measurements of M30 (30min). The bars for SODAR represent standard deviations, whereas for all other variables they represent the minima to maxima range at each station.*

Table 1 Flow characteristics of both valleys

Characteristics IOP# 15	*VDC*	*VDD*
Height max jet speed agl [m]	50	175
Jet maximum [m/s]	2-3	6
Depth flow [m]	100	300

6 Conclusions / Future work

Radiation divergence is regularly observed during KASCADE leading typically to values of **longwave heating (cooling)** rates of -1 to -1.5 K h^{-1}. Observed LHR accounts for around 50% of the observed global heating (cooling) rate during IOP#15. Further investigation should clarify which other factor(s) is (are) missing.

SBL leads to katabatic flows:
- VDC creates in SBL-conditions a weak but consistent **drainage flow**, its depth is of the same order of magnitude as the valley depth.
- VDD-wind is observed with characteristics of both **drainage flow** and **low level jet**, further research should clarify its origin. Besides, this should make clear whether the VDD-wind originates from 1) the lower Durance middle valley, 2) is a consequence of drainage of the "Plateau de Valensole" (Fig. 1).
- Several turbulent layers are observed which are of major importance for **dispersion of pollutants** emitted at the centre of Cadarache.

* In a future stadium:
- Validity check of the 1D-analysis and quantification of observations made.

The 2nd part of the PhD-thesis will be focused on high-resolution modelling by means of WRF.

Literature

Steeneveld, G.J., et al (2010) Observations of the radiation divergence in the surface layer and its implication for its parameterization in numerical weather prediction models, *J. Geophys. Res.*, *115*, D06107, doi:10.1029/2009JD013074.