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CURIE: a new clear air Doppler radar dedicated to the lower part of the Atmospheric Boundary layer (20 m- 750m)

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Abstract. A new X-band miniradar, the CURIE radar (*Canopy Urban Research on Interactions and Exchanges*), mainly adapted to low Atmospheric Boundary Layer sounding has been developed at CETP. After a brief description of the opportunity and working conditions in a turbulent atmosphere, main characteristics are presented. Though this radar works in presence of precipitation as all X-band radar can do, this paper is more dedicated to clear air used in the turbulent atmospheric boundary layer. We are presented comparisons with UHF observations and boundary layer information which can be inferred from CURIE as entrainment across the inversion layer.

1. Introduction

Air dynamics knowledge in the lower atmosphere is necessary for several kinds of investigations especially with the need for a fine spatial vertical resolution close to 20 m in the first 500 m of the *ABL (Atmospheric Boundary Layer)* and with a first level of observation as low as possible. For example pollution studies have to be connected to the *UBL (Urban Boundary Layer)* and exchange at the top of the city itself which concerns particularly the city canopy. This zone is usually covered by Sodar and Lidar measurement but:

- Sodar is not very efficient in very noisy environments as (edges of highway, some urban areas...). More, Sodar noise itself does not seem to be socially accepted by city inhabitants. However as shown by Little [1], acoustic reflectivity (for Sodar) is larger than electromagnetic reflectivity (for radar) in the ABL but this superiority vanishes in presence of large acoustic noise;
- Lidar may be unable to work correctly in very low atmospheric layers in case of too many particles and intense low level fogs...Above typically 500 m height, ST Radar (UHF, VHF) and Lidar are indisputably privileged instruments.

These considerations indicate an interest to develop an instrument equivalent to Sodar but not sensitive to ambient acoustic noise and with no acoustic noise generation. For that purpose, we have developed

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a new X-band Radar CURIE (*Canopée Urbaine Radar pour l'étude des Interactions et Echanges*) for Urban Canopy Radar study of Interactions and Exchanges.

X-band was chosen because small antennas can be used, which is easy in an urban configuration. The possibility to develop low power and less expensive radar using solid state transmitter system was also another reason. However, an important question was the feasibility of clear air Bragg scattering for centimeter wave lengths in the inertial subrange i.e. close to the dissipation range. However several observations (for acoustic waves) using for example 6 kHz up to 20 kHz have shown convincing turbulent Bragg responses, (see Kallistratova [2], Monin [3]) corresponding to λ_{Turb} between 0.8 cm and 2.5 cm. For centimeter electromagnetic waves it must be the same, Tatarskii [4]. CURIE results will show that this assumption was relevant. Notice that the Kolmogorov dissipation scale in the low boundary layer is close to one mm.

Another important point is the minimum of turbulence to be detected. To be very sensitive to turbulence in the ABL, CURIE reflectivity, in term of C_n^2 , should be at least of $10^{-16} \text{ m}^2 \text{ s}^{-2/3}$, see Neff and Coulter [5].

In this paper after CURIE radar and data processing description in section 2, we present several CURIE observations in the low clear air ABL in section 3. Some conclusions and perspective of CURIE use are then presented.

2. Radar description and data processing

CURIE is a pulse coded X-band Radar. Two Prototypes were developed: the first prototype or demonstration prototype was implemented to demonstrate that CURIE can give relevant atmospheric results in clear-air ABL. Radar characteristics were: wavelength: $\lambda = 3.2 \text{ cm}$, 10 W: peak power (solid state amplifier), pulse length: 200 ns, ambiguity distance: 150 m, antenna: parabolic, diameter 1.2 m, gain 40 dBi and beam angle 2° . More information about this prototype and results can be shown in Weill et al. [6].

The second prototype is implemented for scientific purpose: study the atmospheric properties (turbulence, precipitation ...). Description of this prototype is listed in table 1. An offset antenna is used to minimize the effects of secondary beams and ground clutter (fixed echoes). Orientation of this antenna is piloted thanks to an azimuth elevation positioning where we can change automatically the orientation using a positioning system. The received signal is amplified, and then sampled with the intermediary frequency.

60 MHz signal generation (BPRK and pulse modulation), digital receiver, coherent integration, decoding and emitting are programmed in a FPGA. Radial Doppler velocities averages are then processed which provides reliable measurements from an altitude of about 40 meters (to be improved) above ground level and its maximum range, depending on the chosen coded mode is about 720 m (if 16 momentum codes are used).

The Radar processes 4096 FFT points, 300 coherent integrations that correspond to a spectrum every 3 second. CURIE data are then analyzed using Matlab where Doppler spectrums are averaged, smoothed to discriminate and to eliminate noisy information.

Due to different kinds of scatter mechanisms associated with turbulence or with rain drops two types of reflectivity are used:

- In presence of turbulence:

$$\eta = 0.38 C_n^2 \lambda^{-1/3} \quad (1)$$

Where $\eta \text{ (m}^{-1}\text{)}$ is the scattering cross section, $C_n^2 \text{ (m}^{-2/3}\text{)}$ is the refractive index structure function.

- In presence of hydrometeors:

$$\eta = \frac{\pi^5 |K|^2}{\lambda^4} Z \tag{2}$$

Where $|K|^2$ is a function of the complex index of refraction (depending on the electric properties of water) and Z is the radar reflectivity factor.

Notice that mixed cases can also occur.

Table 1. Description of scientific Prototype of CURIE

Characteristic	Value
Frequency	9.42Ghz
Pulse width : -Biphasic mode	160 ns
-Coded mode (Spano code)	4, 8 , 16 moments
Repetition period	0.6 μ s to 4.8 μ s
Spatial resolution	24 m
Antenna Gain	40 dBi
Aperture	1.9°

3. Results

3.1. CURIE Results

CURIE Radar is located inside SIRTA (an experimental site, for more information see <http://sirta.ipsl.polytechnique.fr/>) at Palaiseau. Measurements were performed mainly during 3 periods in 2007. The first period is between March, 21 and April, 15 2007, the second period in May (~10 days) and the last period is during September (2 days). Raw primary data were processed and stored, using Labview, in 1 hour files. Using the positioning system, CURIE can point automatically along different directions (elevation and azimuth). In the 2 first periods of data, radar was positioned in vertical direction, so velocity measured was the vertical velocity and the last period is to test the positioning system, for horizontal wind profiling, Every 2 minutes antenna was pointing in a different direction, then radar was fixed with an angle equal to 15° with the vertical axe.

Different parameters (power spectrum, Doppler velocity, standard deviation of the Doppler velocity, refractive index structure function ...) are calculated.

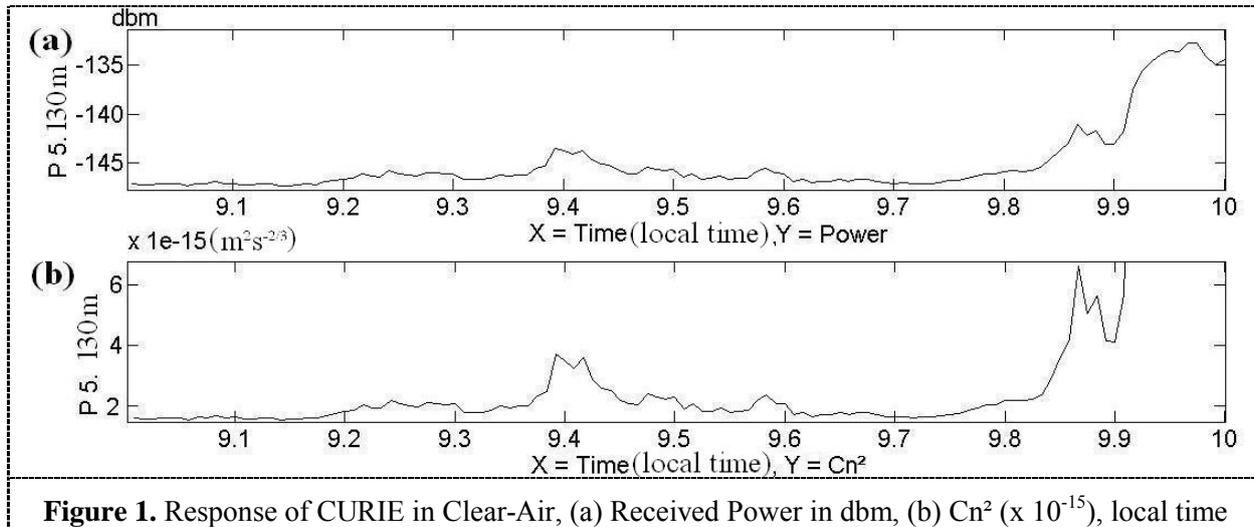


Figure 1. Response of CURIE in Clear-Air, (a) Received Power in dbm, (b) Cn^2 ($\times 10^{-15}$), local time

Figure 1 show the response of CURIE in Clear-Air, this data was collected during March, 31, 2007 at 9h AM (France Time), at an altitude of 130 m (P 5: 5th port). In (a) we plot the power spectrum as a function of time. Signal remains relatively stationary up to the last 10 minutes, where the power increases rapidly due to initiation of a precipitation. In (b), refractive index structure function was calculated using equation (1). In this equation, the scattering cross section η is computed using the equation of radar in clear air. During the last 10 minutes, we cannot talk about Bragg scattering since Rayleigh scattering due to rain drops occurs. The order of magnitude of Cn^2 is larger than $10^{-16} \text{ m}^2 \text{ s}^{-2/3}$.

3.2. A tentative to determine entrainment flux across inversion layer

It is well known that boundary layer evolution is determined by dynamics of exchange across inversion layers and is related to the entrainment fluxes. Ball [7] quoted by Tennekes [8] suggested that entrainment flux was related to vertical kinetic energy across the inversion layer and this concept was used with Sodar; see Weill and Lehmann [9]. A rough estimate of entrainment fluxes Q_i was proposed:

$$Q_i = -A \frac{\sigma_w^3}{h} \quad (3)$$

Where A is close to 1.4 and h is the height of the inversion.

This entrainment flux is reduced to the virtual sensible heat flux if wind shear vanishes (clear air convective case) but is generally associated with momentum production in the wind shear and buoyancy production at the inversion level h:

$$Q_i = - \left(A_1 U_*^2 \frac{dU}{dz} + B_1 \frac{g}{\theta_v} \langle w' \theta'_v \rangle \right) \quad (4)$$

Where A_1 and B_1 are constant, U_* is the friction velocity, U the mean wind, z the height, θ_v the mean virtual potential temperature and $\langle w' \theta'_v \rangle$ the mean local virtual temperature flux.

Notice that virtual temperature is used due to wet air entrainment across the boundary layer. This mechanism is responsible for cloud formation; see Mathieu et al. [10].

Figure 2 shows estimates of entrainment fluxes from (3), just before precipitation, with data collected on March, 29, 2007, local time. Of course, these raw estimations of entrainment fluxes must be

validated and compared to cloud parameterization and modeling with different mechanisms as suggested in [10] as bulk Richardson number. Comparisons with surface fluxes have also to be undertaken. More, dry and wet buoyancy components due respectively to sensible and latent heat fluxes must be taken into account.

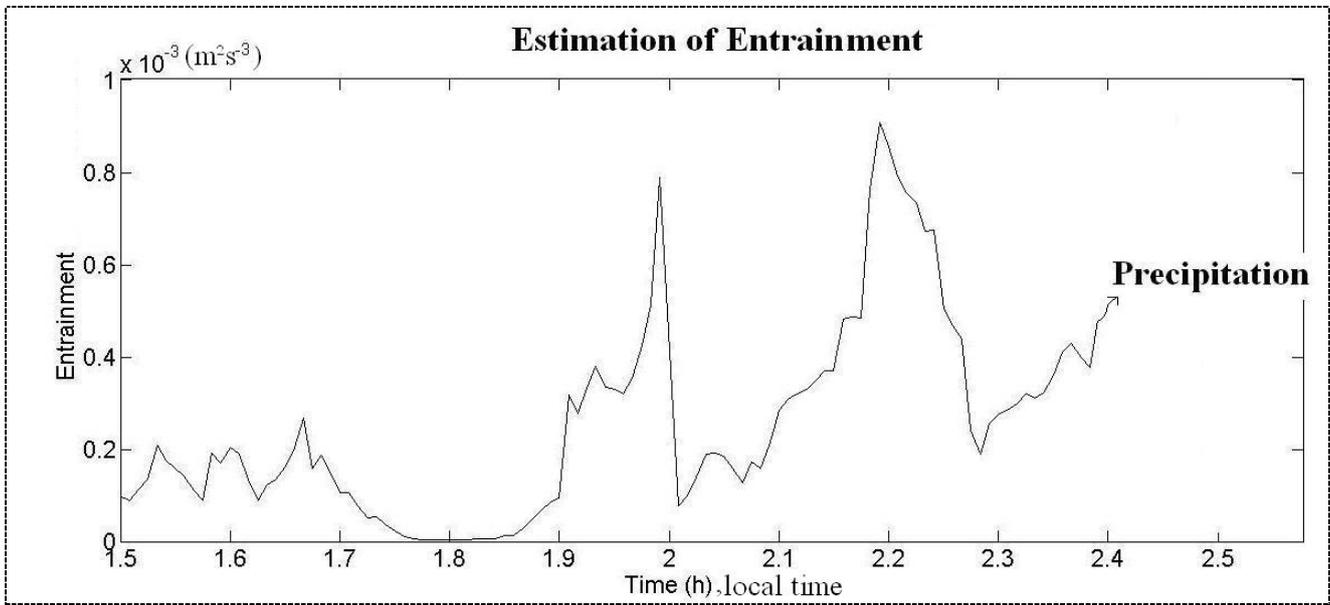
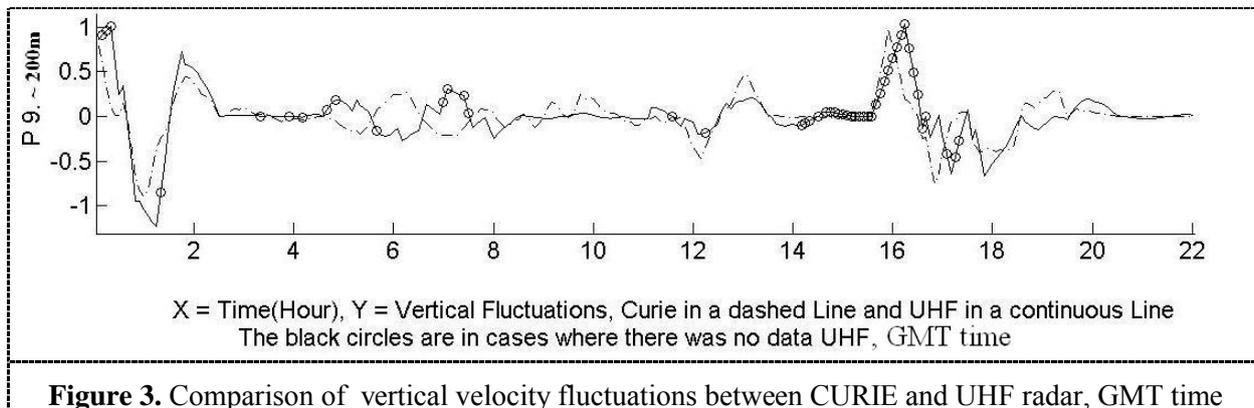


Figure 2. Estimation of the entrainment (m^2s^{-3}), local time.

3.3. Comparison with UHF Radar

The UHF Radar Deg rewind PCL1300 is used by EDF (Electricité De France) to study the wind profiling; it is located in SIRTA near CURIE Radar. Its average power is 3.5 watts (using an amplifier as power equal to 500w and pulse width equal to 350ns), broadcasts at a frequency close to 1.238 Gigahertz, ($\lambda = 24$ cm). The Radar antenna is made up of five panels necessary for the formation of the five beams (one vertical and four oblique beams). The other four oblique beams are made from four panels tilted 17° from the horizontal. Each panel consists of a network composed of eight antennas. The radar antenna is usually surrounded by a fence designed to reduce ground clutter from around fixed objects (trees, buildings ...). It detects the radial Doppler velocity within a volume resolution that has an aperture of 8.5° . It provides reliable measurements from an altitude of about 85 meters above ground level, which has been proved in campaign measurement in Lannemezan (South West of France), and its maximum range, which depends on the intensity of the echoes from the atmosphere, is about 1500 to 2000 m. Note that signal received has been reduced using an HS switch in the receiver.



Data coming from this Radar are stored in 5 minutes files, but each file from this radar corresponds to moving averages (averages on 30 minutes delayed every 5 mn).

Figure 2 shows a comparison of vertical velocity fluctuations between CURIE and the UHF Radar, after elimination of a negative mean average bias associated with each radar and of same order of magnitude. In this Figure, we plot CURIE vertical fluctuations (in dashed line) and UHF radar fluctuations as function of time (GMT time in hour); at an altitude of 200 m (P 9: gate 9th), this data was collected on March, 30, 2007. The black circles correspond to cases where data were not validated. We can observe a good correspondence between these two graphs. This relatively good correlation seems to be systematic at least for concomitant observations but differences must be understood due to the different wave lengths and the different radar characteristics.

4. Conclusion

CURIE is course in development and validation and seems to be adapted to «urban micrometeorology».

This radar has been indeed designed for low atmospheric boundary layer profiling. In this paper, we only present first interesting observations in clear air:

- Turbulence observation in the boundary layer and Cn^2 evaluation.

This shows that CURIE sensibility is what was awaited, but systematic comparisons during different conditions, with independent estimations remains fundamental to understand if turbulence response corresponds to inertial turbulence.

- Raw analysis of entrainment across a stable layer just before cloud evolution toward precipitation.

This type of analysis is necessary if we have to take into account that CURIE can be applied to clear air physics as well as precipitation physics in the ABL.

- A comparison of vertical velocity fluctuations with UHF Radar.

It shows convincing results about measured variables but suggests to go further into scatter mechanisms at different wave lengths to explain discrepancies.

Different works are in progress:

- Systematic validation of CURIE during different ABL conditions;
- Precipitation analysis;
- Discrimination of turbulence in presence of precipitation.

We have only described a few examples of results as obtained with a vertically pointing antenna, but in the future the orientation capabilities of CURIE will be used for horizontal wind profiling. For that

purpose, real time processing will be improved using fast response relevant operational algorithms. If CURIE is intended to work for urban micrometeorology, CURIE has also some capabilities to work on MABL (Marine Boundary Layer).

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