CIBA2008, una campaña experimental de la capa límite atmosférica: resultados nocturnos preliminares

CIBA2008, an experimental campaign on the atmospheric boundary layer: preliminary nocturnal results

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RESUMEN

Durante junio de 2008 se desarrolló una campaña de medidas en la Capa Límite Atmosférica en el CIBA (Centro de Investigaciones de la Baja Atmósfera), que se encuentra sobre un extenso páramo de la meseta norte (41º49' N, 4º56' W) de características de terreno homogéneo. Se ha dispuesto de instrumentación sobre una nueva torre meteorológica de 10 m, que incluye en varios niveles sensores de temperatura y humedad, anemómetros de cazoletas y veletas, así como un anemómetro sónico. Se disponía de dos microbarómetros con tecnología de cuarzo en los niveles de 50 y 100m sobre la torre principal (100 m) del CIBA. Además, tres microbarómetros adicionales se situaron en una disposición triangular de unos 200 m de lado en la superficie. Por otra parte, se utilizó un globo cautivo para la determinación de perfiles verticales de temperatura, viento y humedad hasta 1000 m de altura. Finalmente, un monitor de partículas GRIMM (MODELO 365), que permite la medida simultánea y continua de PM10, PM2.5 y PM1 cada 6 segundos, se instaló a 1.5m del suelo.

Este trabajo mostrará algunos resultados preliminares de la campaña CIBA2008, analizando los principales procesos físicos presentes en la Capa Límite Nocturna (NBL), los diferentes periodos de estabilidad observados y los correspondientes parámetros turbulentos, así como las estructuras coherentes detectadas. Las perturbaciones de presión medidas en los diferentes microbarómetros permiten estudiar los principales parámetros ondulatorios a través de transformadas *wavelet*, y comparar dichas estructuras con las detectadas en los registros de viento y de partículas.

Palabras clave: Capa límite nocturna; campaña experimental; parámetros turbulentos; mezcla intermitente; estructuras coherentes; concentración de partículas.

ABSTRACT

An Atmospheric Boundary Layer campaign was developed in Spain during June 2008 at the CIBA (Research Centre for the Lower Atmosphere) site which is placed on a fairly homogeneous terrain in the centre of an extensive plateau (41º49' N, 4º56' W). Different instrumentation at several levels was available on a new 10m meteorological mast, including temperature and humidity sensors, wind vanes and cup anemometers, as well as one sonic anemometer. Besides, two quartz-based microbarometers were installed at 50 and 100m on the main permanent 100m tower placed at CIBA. Three additional microbarometers were deployed on the surface on a triangular array of approximately 200 m side, and a tethered balloon was used in order to record vertical profiles of temperature, wind and humidity up to 1000m. Finally, a GRIMM particle monitor (MODEL 365), which can be used to continuously measure every six seconds simultaneously the PM10, PM2.5 and PM1 values, was deployed at 1.5m.

This work will show some preliminary results from the campaign CIBA2008, analysing the main physical processes present in the atmospheric Nocturnal Boundary Layer (NBL), the different stability periods observed and the corresponding turbulent parameters, as well as the coherent structures detected. The pressure perturbations measured from the surface and tower levels make possible to study the main wave parameters from wavelet transform, and compare the structures detected by the microbarometers with those detected in the wind and particles records.

Key words: Nocturnal boundary layer; field campaign; turbulent parameters; intermittent mixing; coherent structures; particle concentration.

SUMMARY: 1. Introduction. 2. Data and instrumentation. 3. Results. 4. Summary and conclusions. 5. Acknowledgements. 6. References

1. INTRODUCTION

The Atmospheric Boundary Layer (ABL) is directly influenced by the earth's surface through both dynamic and thermal effects. At night it is often cooled and forms a stable layer known as Stable Boundary Layer (SBL) or, also, Nocturnal Boundary Layer (NBL) (Stull, 1988). Many phenomena happen in the SBL: radiative flux divergence, low-level jets, intermittent and patchy turbulence, shear instabilities, wave generation and breaking or fog formation (Viana et al., 2008) among others. Moreover, there are some important influences of these processes in the evolution and behaviour of air pollution in the ABL. Some examples are the diffusion of atmospheric properties and components depending on the different physical conditions and processes present, being especially important wind speed, wind shear, turbulence and stratification (Arya, 1999).

At night, the mechanical generation of turbulence and the damping produced by stability can change quite quickly, leading to different level of turbulent mixing, which sometimes is intermittent or sporadic. In order to reach a better knowledge of the behaviour of the NBL and the physical phenomena related to it, several experiments have been developed for the last years, both in mid-latitudes (Cuxart et al., 2000; Poulos et al., 2002; Yagüe et al., 2007; Conangla et al., 2008) and at polar sites with strong stability conditions (Grachev et al., 2005).

One interesting point to study is the influence of stability and the nocturnal cooling on the fog formation, looking for the relationship between fog and turbulence because the physical processes involved in its evolution are not yet completely understood. In particular, the role of turbulence in the evolution of radiative fog remains as one of the most controversial points. The combination of different theories, some establishing that turbulence inhibits the radiative fog formation (Roach et al., 1976) and by contrast, some supporting that it constitutes a contributing factor (e.g., Welch and Welicki, 1986), leads to the conclusion that there is a threshold relationship between turbulence and fog formation (Zhou and Ferrier, 2008). It is interesting to analyze the behaviour of the NBL in presence of fog, including the use of vertical profiles of temperature, wind and relative humidity, since the exchange of energy as turbulent flux, sensible and latent fluxes may be contribute to fog development (Terradellas et al., 2008).

On the other hand, another key point to study in the SBL is the relationship between turbulence and waves, especially internal gravity waves, which often appear in stable conditions; some recent work has focused in this issue (Nappo, 2002; Viana et al., 2009). These waves can be detected by studying pressure variations at a certain fixed level above the surface.

In this paper the preliminary nocturnal results of the CIBA2008 field campaign will be presented, considering some of the processes described above. The main objectives are: a) Study the main physical processes present in the NBL, the different stability periods observed and the corresponding turbulent parameters; b) Analyze the coherent structures detected in stable situations from different records (pressure, wind, particle concentrations –PM–).

2. DATA AND INSTRUMENTATION

During June 2008 an intensive field campaign (CIBA2008) took place at the CIBA (Research Centre for the Lower Atmosphere) site which is placed around 30 km NW from Valladolid city on a fairly homogeneous terrain (San José et al., 1985) in the centre of an extensive plateau (41º49’ N, 4º56’ W). For further information on the CIBA site and other related campaigns, see Cuxart et al. (2000). Eight consecutive days of this campaign (14-21 June 2008) have been analyzed in order to obtain a complete evolution of the properties in the NBL under different synoptic conditions.

Instrument	Heigth (m)	Sampling rate (Hz.)	Measured variables
Sonic anemometer	10	20	u, v, w, T
Cup anemometer and vanes	1.5 – 3 – 5 – 7.5 – 10	1	$\left\lvert \vec{V}_H \right\rvert$, α
Thermometers and humidity sensors	1.5 – 10	1	T, RH
Microbarometers (PAROSCIENTIFIC)	50 – 100 – surface array	2	p
GRIMM 365 monitor	1.5	1/6	PM10, PM2.5, PM1
RASS – SODAR	surface	-	u, v, w, T

Table 1. Instruments used during CIBA 2008 field campaign.

The measurements collected in CIBA 2008 come from four sources (see Table 1 for further details):

1. Instrumentation placed in a 10m meteorological mast, including a sonic anemometer (at 10m height), cup anemometers and vanes (1.5, 3, 5, 7.5 and 10 m) and temperature and humidity sensors (1.5 and 10 m).
2. A 100m tower equipped with PAROSCIENTIFIC microbarometers, which measure absolute pressure at 2 Hz. With this sample rate, a precision nearly 0.002 hPa is obtained, so it is a good tool to detect coherent structures (gravity waves, K-H waves, etc) of typical amplitude 0.01-0.1hPa and periods of the order of minutes, as well as more rapid perturbations from turbulent origin.
3. At surface (which means around 1.5m above from ground level) there were: 3 microbarometers on a 200m side triangular array, in order to characterize coherent phenomena (period, wavelength, phase speed and direction) propagating along CIBA site (Viana et al., 2007); a GRIMM 365 monitor, to measure particles concentration according to their equivalent radius: smaller than 10 µm (PM10), 2.5 µm (PM2.5) and 1µm (PM1); and a RASS-SODAR, which enables one having an estimation of both temperature and wind profiles, measuring continuously.
4. A tethered balloon, from which 63 soundings up to 200-900m (according to wind conditions) were made.

3. RESULTS

In this section we present the evolution of the main parameters evaluated for different nights of CIBA 2008, describing in detail two contrasting nights.

3.1 Main parameter evolutions during CIBA2008

Figures 1 and 2 show the evolutions of mean meteorological variables and stability (Temperature difference between 10m and 1.5m, bulk Richardson number; see Appendix A for definitions) for the 8 days studied. The period from 1800 to 0600 GMT will be considered to analyze the NBL, including the transition from the late diurnal conditions to the nocturnal ones (sunset is around 2000GMT) and the diurnal transition (sunrise around 0445GMT).

Two quite different periods are found: 4 nights with a weakly stable to near-neutral NBL (13-14, 14-15, 15-16 16-17) and 4 nights where stronger stable conditions are developed (17-18, 18-19, 19-20, 20-21). Synoptic conditions were also different. Stable nights are characterized by low winds, development of strong surface-based inversions, and positive and high Bulk Richardson number (a value of 0.5 has been taken as critical R_B in Fig.1c –dashed line–).

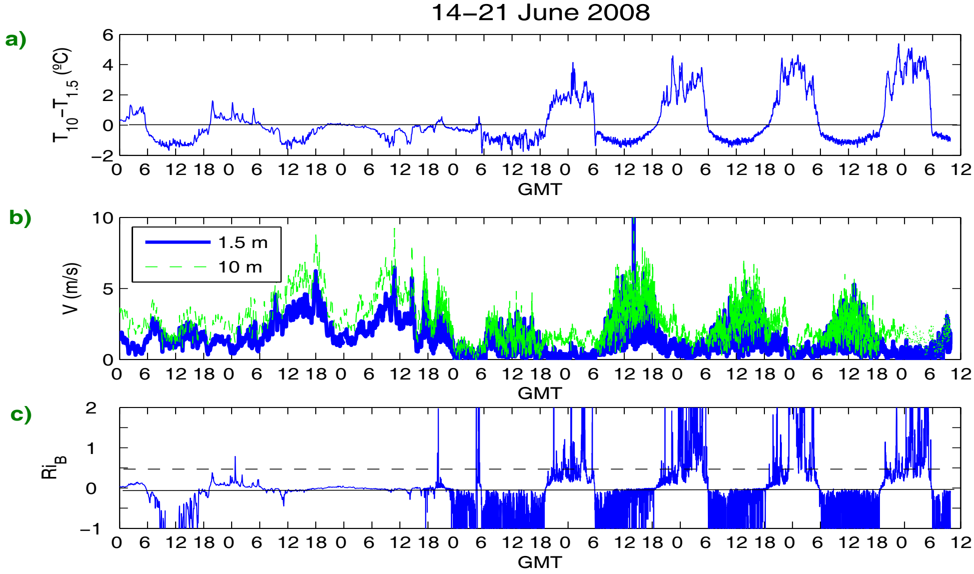


Figure 1. Temperature difference between 10m and 1.5m (a), wind speed at 10 (higher values) and 1.5m (b) and Bulk Richardson number (c) from 14 June to 21 June 2008.

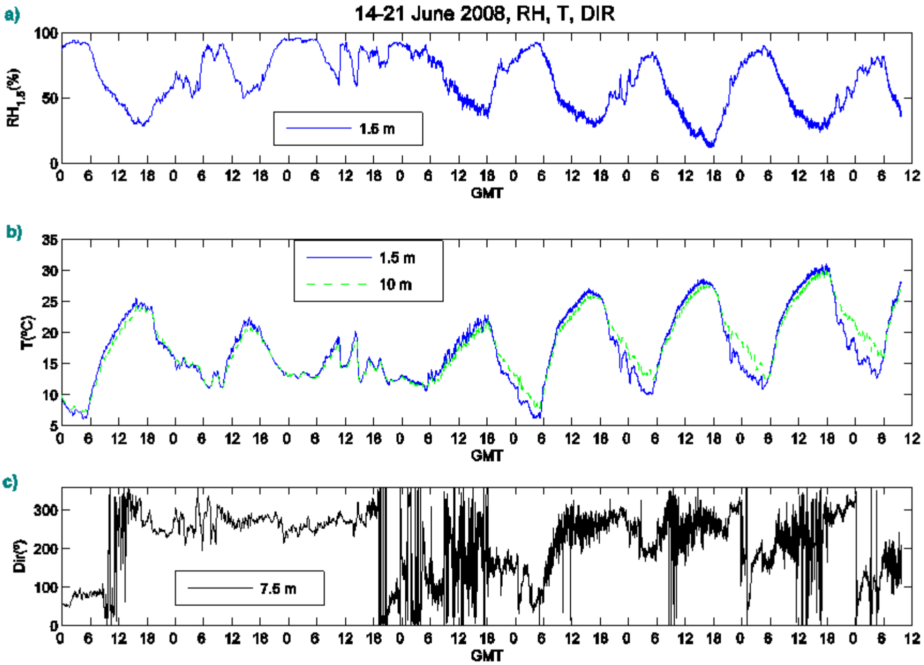
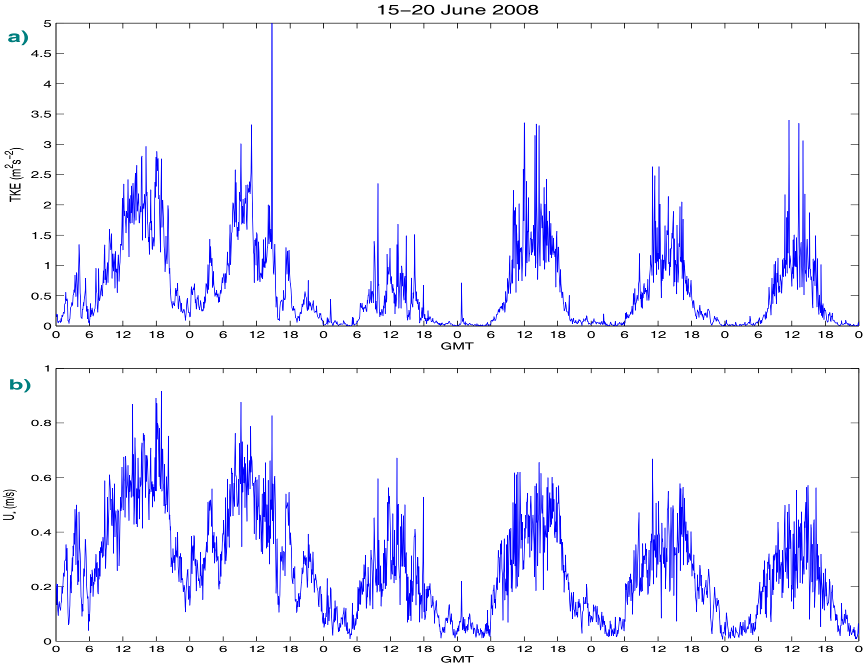


Figure 2. Relative humidity at 1.5m (a) Temperature at 1.5 and 10m (b) and wind direction at 7.5m (c) from 14 June to 21 June 2008.



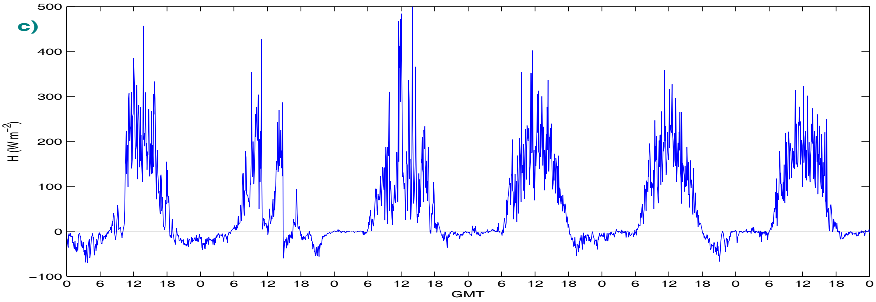


Figure 3. Turbulent Kinetic Energy (TKE) (a) Friction velocity (b), and sensible heat flux (c) evolutions from 15 to 20 June 2008.

The Relative Humidity (RH), shown in Fig. 2a, plays a very important role both in the nocturnal evolution of the temperature and in the stability developed (Viana et al., 2008). High values of RH (13-14, 15-16, 16-17) lead to small decreases of the nocturnal temperature and to near-neutral NBLs, even in presence of low winds (16-17).

Turbulent parameters (5 min. averages) are shown in Fig. 3 (see Appendix A for definitions). TKE and friction velocity (U_*) are very well correlated and detect the turbulent periods of the nights, and the stable ones too.

Figure 4 shows the variations of PM concentrations (PM10, PM2.5 and PM1). Although minimum values are generally found at diurnal times and maxima are achieved at nocturnal hours, the greatest differences between day and night are found for the second period analyzed (18-21 June), where stronger stable nights and more convective days are present. This could be related to the small (big) capacity of the low atmosphere to diffuse the particles during stable nights (convective days). However, a clear correlation between different parameters is not seen.

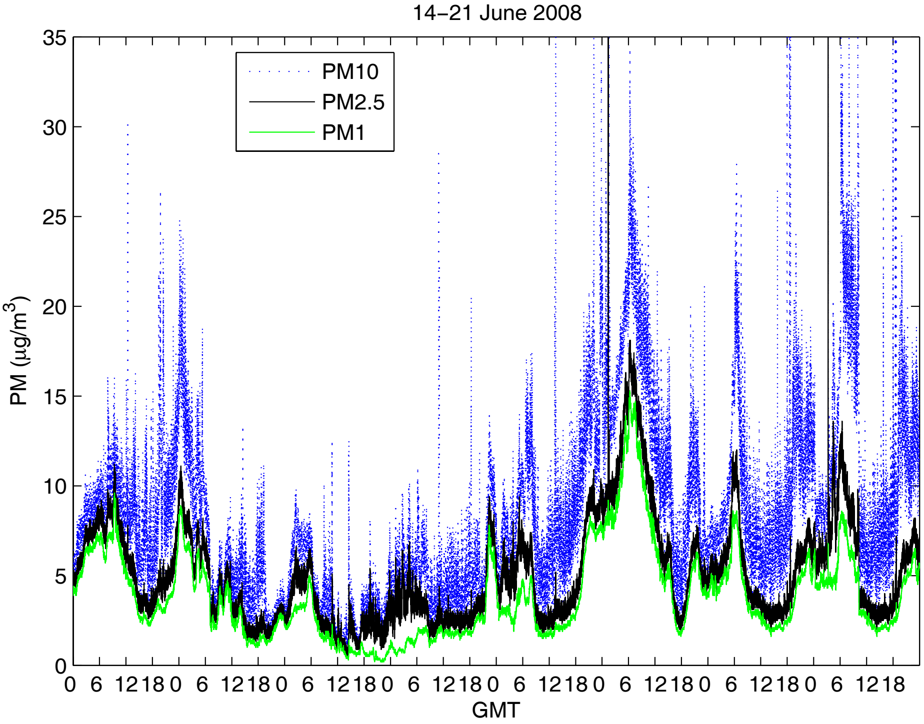


Figure 4. PM10, PM2.5 and PM1 evolutions along the 8 days analyzed (14-21 June 2008).

Although the scatter is high, a decreasing tendency in PM10 is found for the stronger turbulent conditions (friction velocity) and wind speed, which corresponds to a higher diffusive capacity of the lower atmosphere (Fig. 5). The largest values in PM10 are not found for the lowest wind, but around 2 m s^{-1}. These results are similar for PM2.5 and PM1 (not shown). In Fig. 6 we can see the correspondence between variations in turbulent conditions and in PM2.5. The maximum values in PM2.5 coincide with low values in turbulent parameters (U_* and TKE). The evolution of the 18-19 night (Fig. 6-down) shows the so small values of turbulent parameters achieved this very stable night and how the particles (PM2.5) accumulate close to the ground along the night due to the absence of turbulent mixing.

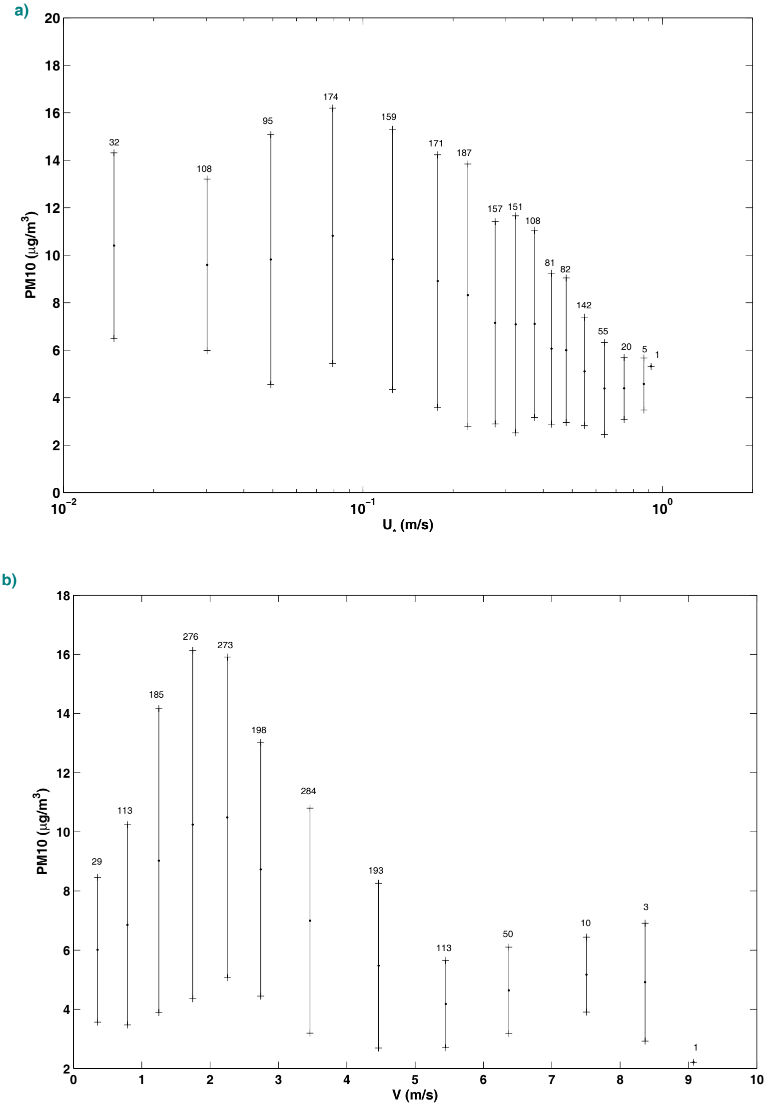


Figure 5. PM10 vs. friction velocity (a) and vs. wind speed (b). Over the bars are shown the number of events considered for each point. Vertical bars indicate the standard deviation of these events.

3.2 15-16 June NIGHT versus 18-19 June

The 15-16 night is characterized mainly by a near-neutral NBL, driven by moderate winds. The high values of Relative Humidity (close to 100% from 2200GMT onwards) avoid the developing of both surface cooling and a stable layer (Figs. 1c and 2b). No coherent structures are detected by the microbarographs, and much lower values of PM concentrations are measured compared to the nocturnal stable period.

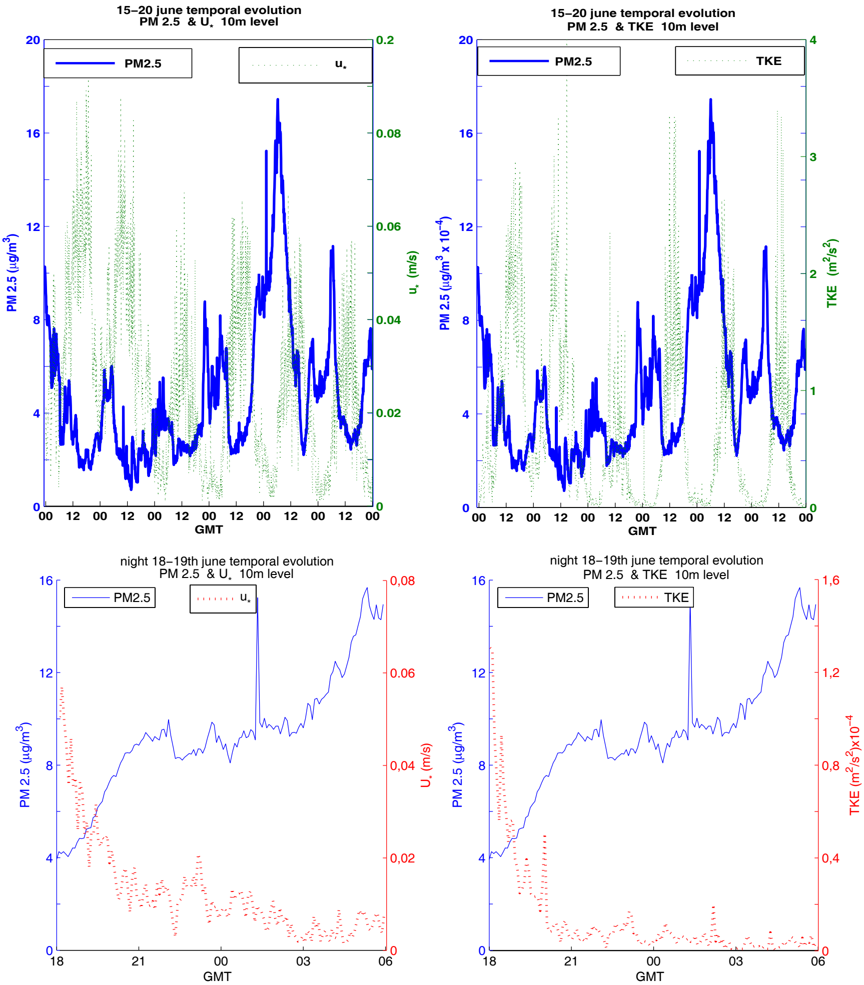


Figure 6. PM2.5 vs. friction velocity (left) and vs. TKE (right) temporal evolution from 15 to 20 June 2008 (up), and the same for the 18-19 night (down).

On the other hand, the 18-19 night (Fig. 7) presents high supercritical values of Richardson number (Fig. 1c). Surface-based inversions up to 200m are detected by the soundings, whereas maxima values of PM are found, especially at the end of the night. Oscillatory behaviour of different records (temperature, wind or PM) can be seen along the night. Different coherent structures are detected by wavelet analysis (Fig.8). The same structures are detected by the microbarometers at surface, 50m and 100m (Fig. 8a). These structures are found during periods with strong stability. Not all these structures are found in wind speed, showing non-linear interactions between pressure and wind along the night. Different structures (not shown) are detected when bigger (PM10-PM2.5), median (PM2.5-PM1) or smaller (PM1) particles are considered.

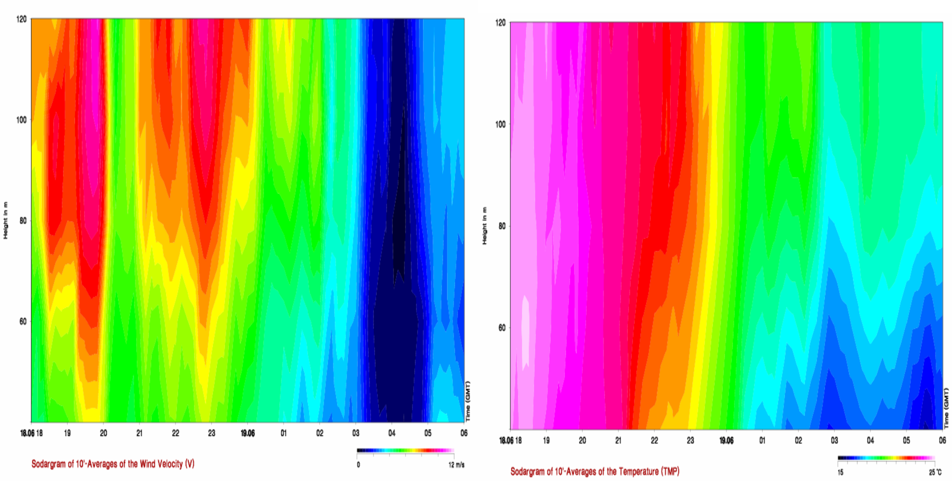


Figure 7. Vertical structure of wind speed (left) and temperature (right) for the 18-19 night obtained from SODAR (1800 to 0600 GMT).

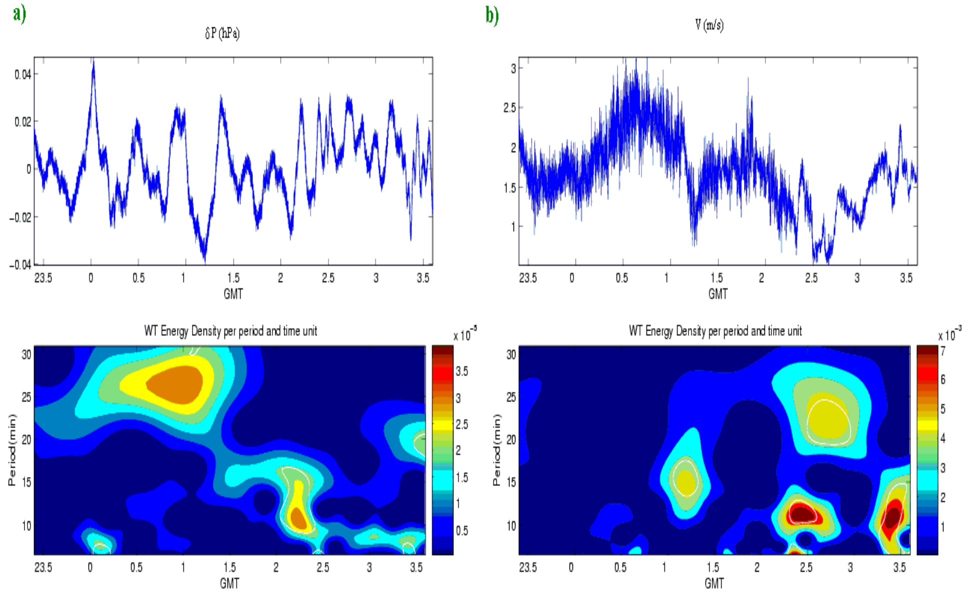


Figure 8. Wavelet spectra along the 18-19 June night for different variables: pressure at surface (a), sonic wind speed (b).

4. SUMMARY AND CONCLUSIONS

Some preliminary results from the CIBA2008 field campaign are presented showing the evolution of mean variables, stability and turbulent parameters for 8 consecutive days:

- Two different periods are found, one controlled by higher winds, sporadic instability with scattered showers leading to a near-neutral NBL, and other with moderate to strong stability, developing important surface-based inversions, which are intermittently eroded by bursts of turbulence.
- An example of the near-neutral NBL is the 15-16 night, with moderate winds which maintain a certain level of turbulence, where it is observed the importance of high values of relative humidity, producing condensation and controlling the surface cooling and the stability.
- An example of the stable NBL is the 18-19 night, with low winds, high Richardson numbers, intermittent turbulence and coherent structures which are present in the different records of pressure, wind or PM concentrations.
- The particle concentrations measured from PM10, PM2.5 and PM1 are sensitive to wind speed, turbulent parameters and local stability conditions, showing different wavelet spectra for the different particle size.

5. ACKNOWLEDGEMENTS

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Queremos dedicar este trabajo a nuestra querida Profesora Elvira Zurita, agradeciéndole su constante apoyo personal en todas aquellas investigaciones que emprendíamos. Siempre nos impulsaste a innovar y a dar lo mejor de nosotros mismos. Nuestro mejor tributo sería emularte, en la medida de nuestra capacidad, tanto en el ámbito docente y académico, como en el arte de eliminar cualquier problema o enfrentamiento. Para ello, tu inolvidable sonrisa permanecerá para siempre en nuestro recuerdo y nos seguirá animando en el futuro.

APPENDIX

In this appendix the different definitions of the turbulent and stability parameters used in section 3.1 are listed:

- Bulk Richardson Number (R_B): This stability parameter comprises information about the dynamic and thermal processes contributing to stability (wind shear and gradient of potential temperature):

$$R_B = \frac{\frac{g}{T_o}\sqrt{Z_1 Z_2}\, ln\left(\frac{Z_2}{Z_1}\right)\Delta\theta}{(\Delta U)^2} \tag{A1}$$

$\Delta\theta=\theta_{10}-\theta_{1.5}$. $\Delta U=U_{10}-U_{1.5}$. U is the wind speed and θ the potential temperature. $Z_1=1.5m$; $Z_2=10m$

- The temperature difference near surface ($\Delta T_{10\text{-}1.5}$), which corresponds to surface-base inversion strength during the night:

$$\Delta T_{10-1.5} = T_{10m} - T_{1.5m} \tag{A2}$$

- The friction velocity (U_*), which includes the momentum flux.

$$U_* = \left[(-\overline{u'w'})^2 + (-\overline{v'w'})^2\right]^{1/4} \tag{A3}$$

- The turbulent kinetic energy (*TKE*), which is the portion of kinetic energy associated with turbulence, evaluated from the variances of the along-wind, cross-wind and vertical components of velocity:

$$TKE = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right) \tag{A4}$$

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