Study of the evening transition to the nocturnal atmospheric boundary layer: statistical analysis and case studies

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1. INTRODUCTION

- Data from three months (Summer 2009) collected at the CIBA[1] (Research Centre for the Lower Atmosphere) site are used to analyze the main characteristics of the evening transition to a Nocturnal Boundary Layer (NBL). See poster XY628 for site characteristics.
- Mean properties of the transition as well as some case studies are shown.
- The temporal interval 17.00-23.00 UTC has been used in the study with 3 subintervals.

Objectives:

- Study the main parameters (surface wind and vertical temperature gradient) controlling the different transitions.
- Analyze the different types of transitions and their influence in the later developing of the NBL: turbulent and stability parameters, PM concentrations or time between the crossover (change of sign in the Sensible Heat Flux) and the sunset.

2. DATA, INSTRUMENTATION AND PARAMETERS

1.-Meteorological mast (10m):

- Sonic anemometer (u, v, w, T): 10m (20Hz).
- Cup Anemometers and Vanes : 1.5 and 10m (1Hz).
- Temperature: 1.5 and 10m (1Hz).
- GRIMM 365 Monitor measuring simultaneously PM10, PM2.5 and PM1 every 6 s.

2.-Mean variables, Turbulent and Stability parameters:

- Five minutes means have been evaluated for wind speed at 1.5m and 10m, temperature difference between 10m and 1.5m, as well as stability and turbulent parameters at 10m (see Appendix I for definitions).
- MultiResolution Flux Decomposition (MRFD)[2, 3] is a multiscale statistical tool which has been used to calculate the contributions of different scales to Turbulent Kinetic Energy (TKE) and Sensible Heat Flux along the transition. (See poster XY628 for details on MRFD).

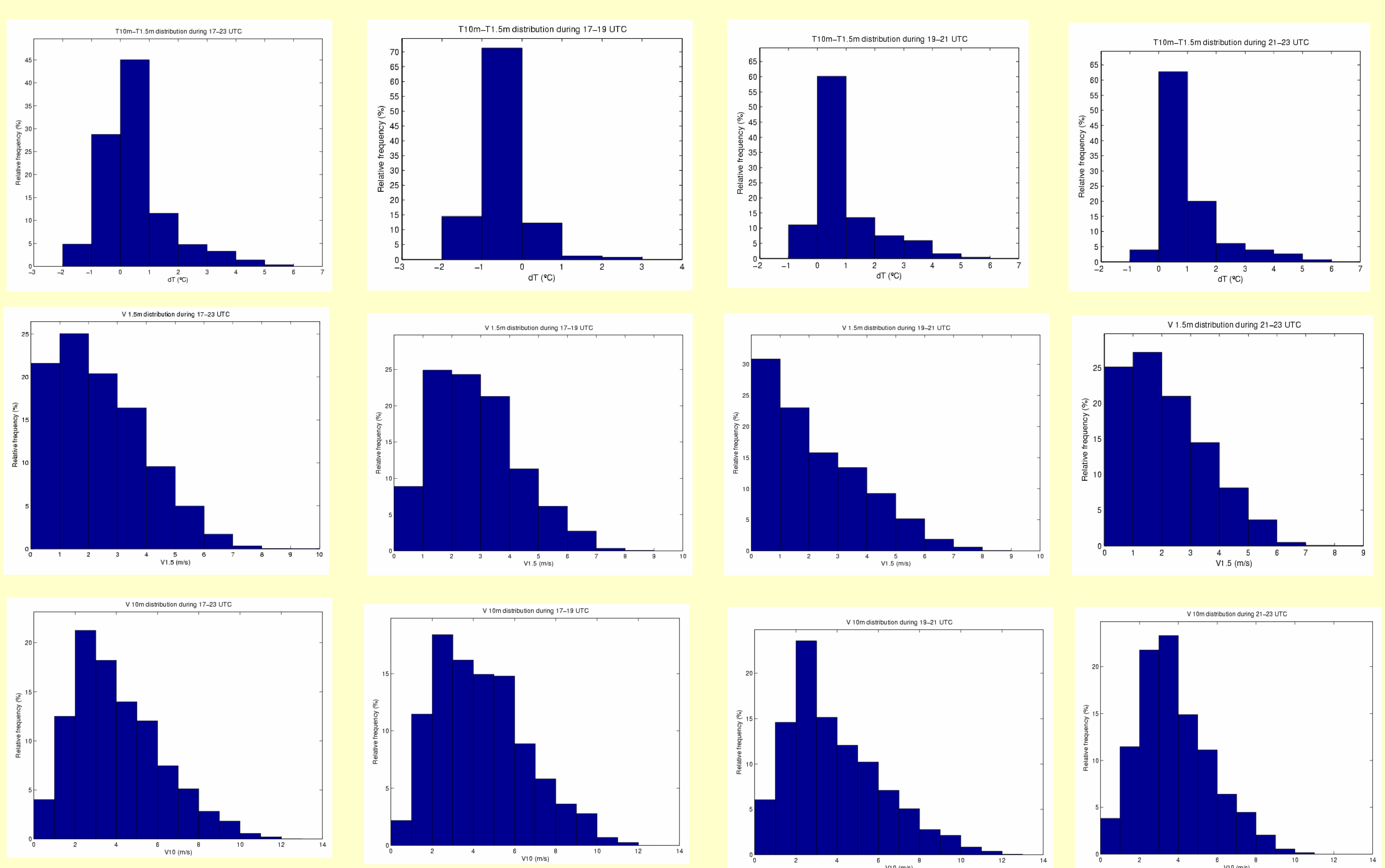


Figure 1: Temperature difference between 10m and 1.5m distribution (up), wind speed at 1.5 m (middle) and wind speed at 10 m distributions for 17-23 UTC, 17-19 UTC, 19-21 UTC and 21-23 UTC (from left to right)

MEAN VALUES	17-19 UTC	19-21 UTC	21-23 UTC
$U_{1.5}$ (m/s)	2.84	2.29	2.20
U_{10} (m/s)	4.41	4.00	3.87
$\Delta T_{10-1.5}$ (ºC)	-0.46	0.87	0.93
Ri_B	-0.12	0.18	0.15
PM1 (µg/m^3)	3.26	5.00	6.94
PM2.5 (µg/m^3)	5.04	7.23	9.06
PM10 (µg/m^3)	12.75	18.70	17.64
TKE (m^2/s^2)	1.16	0.60	0.45
U_* (m/s)	0.39	0.26	0.24
H (W/m^2)	61.58	-13.75	-18.49

Table I: Mean values of wind speed, Temperature difference between 10 and 1.5m, Bulk Richardson number, particle concentrations and turbulent parameters for the 3 time ranges used.

3. RESULTS.

3A) Global evening transitions for Summer 2009

- Fig. 1 shows the distribution of wind speed and temperature difference between 10m and 1.5m for the three months of evening transitions (17-23 UTC) together with the distributions for the 3 sub-periods analyzed. Winds at 1.5m are < 1 m/s for less than 10% of the data in the 17-19 UTC time sub-period, while these so low values are reached for the 30% between 19 and 21 UTC. This decay in surface wind produces an increasing stability in 19-21 and 21-23 UTC sub-periods: In the first sub-period less than 20% of the data present surface-based inversion, reaching 90% in the second sub-period and 96% in the third.
- Table I presents the mean values of wind speed, thermal stability, turbulent parameters and PM concentrations for the 3 sub-periods considered. In general, stability increases along the transition, with decreasing values of turbulence and increasing concentration of particles.

3. RESULTS.

3B) Cases studies

- Fig. 2 shows the two transitions studied in detail. Synoptic conditions are stable in high levels (500 hPa) but the pressure gradient at surface is very different. Day 26th (low winds and very stable conditions at surface) presents surface winds < 1m/s for around 75% of the data and inversion conditions for more than 70% of the data (17-23 UTC) while Day 28th (near neutral stability produced by moderate-strong winds) shows that all the data have winds > 4m/s and temperature difference between 10 and 1.5m is < 0.1ºC.
- MRFD points out that on 26th KE is extremely weak and mainly driven by scales >100s (non-turbulent, mesoscale contributions) while on 28th KE is much more intense and the scales between 1 and 100 s showing turbulent activity prevail. The transition in the turbulent regime is more clearly seen in the sensible heat flux. Nighttime eddies have shorter timescales than convectively-driven eddies; specially in windy, neutrally stratified nights (August 28th), when eddies are bigger than in stable nights, but move faster.
- Nocturnal PM10 concentrations range from 1 µg/m^3 on 28th August to 30 µg/m^3 on 26th, due to the very weak turbulent mixing this last day, favouring the concentrations of particles near the surface. The time lag between the crossover of the flux and the sunset is quite larger for the low winds situation.
- Both days correspond to the last week of August (Fig. 3) where quite different transitions are found (A, B, C). The evolution of the TKE and Sensible Heat Flux for 4 transitions can be found in Figs. 4 & 5.

4. SUMMARY AND CONCLUSIONS

- Evening transitions during Summer 2009 present a high degree of stable cases, with an increasing temperature with height in more than 90% of the data from 19 to 23 UTC. Winds at 1.5m less than 2 m/s are achieved for the 50% of the data for the global period (17-23 UTC). Wind is generally higher before the sunset (17-19 UTC) decreasing quickly the larger values in the distribution for the 19-21 UTC sub-period. The influence of katabatic winds is present in the distribution, especially for the sub-period 21-23 UTC.
- Different kinds of transitions have been found: those controlled by moderate to high synoptic winds (TKE > 2 m^2/s^2; see A in Fig. 4; this transition is not very often in Summer), those with very small winds (TKE < 0.5 m^2/s^2) before sunset (developing early strong surface-based inversions and katabatic winds; see B) or those with small to moderate winds (0.5 < TKE < 1.5 m^2/s^2) before sunset developing a soft continuous inversion along the night, without important katabatic winds (see C).
- The different kinds of transitions (some of them with a very similar synoptic situation) can have a quite different evolution of the NBL depending on the presence (or not) of a katabatic wind, which can erode the strong inversion early developed. MultiResolution evaluation of the KE and Heat Flux shows the influence of the different scales along the transition. Sometimes (very stable nights influenced by the presence of gravity waves [4]), larger scales can have important RELATIVE contributions to KE or Heat Flux

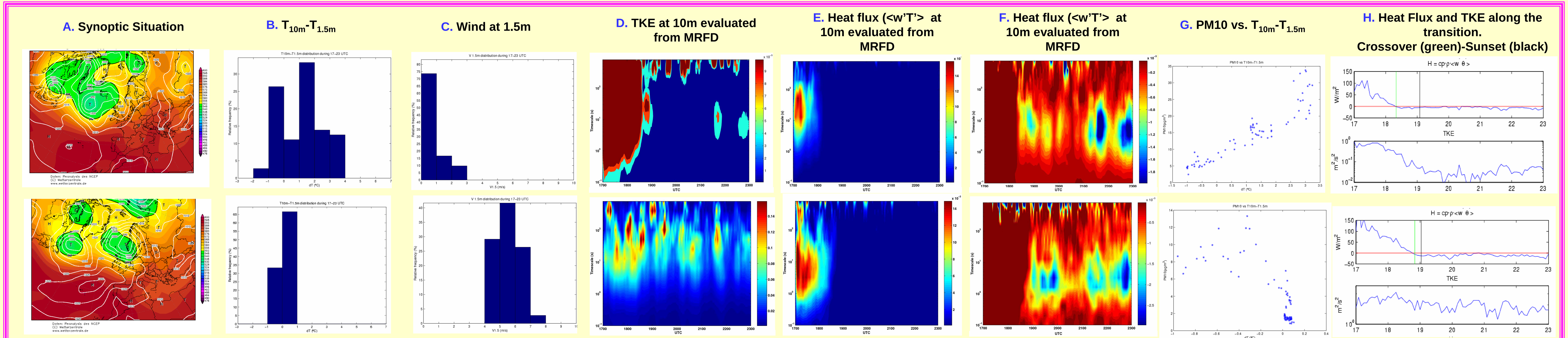


Figure 2: Synoptic situation (MSLP and 500hPa Geopotential) and different information evaluated for the transition (17-23 UTC) belonging to August 26th (up) and 28th (bottom) 2009. Notice the different scales used in the MRFD figures (D, E, F)

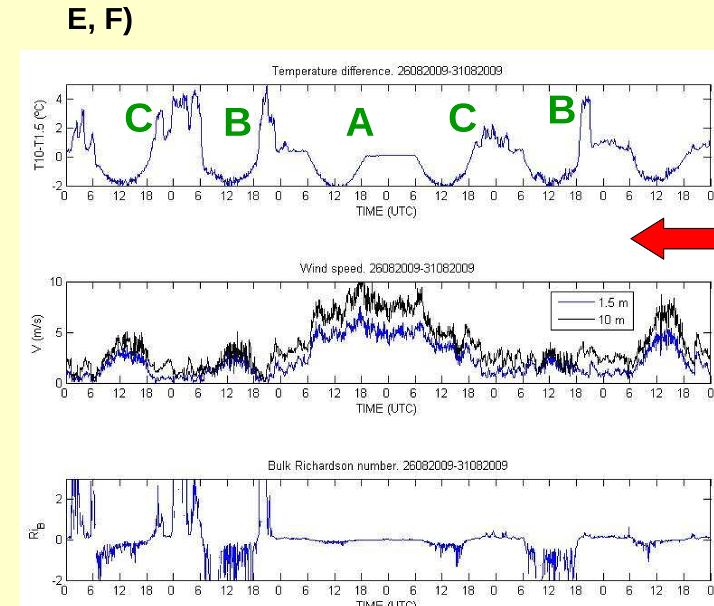
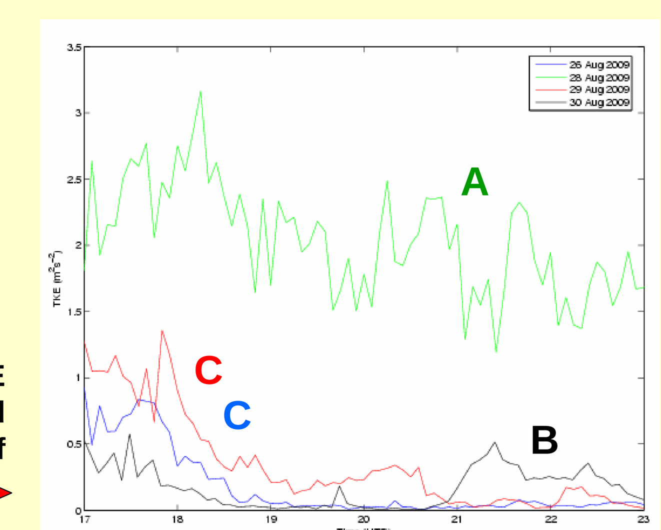


Figure 3: Evolution of temperature difference between 10 and 1.5m (up), wind speed at 1.5 and 10m (middle) and Bulk Richardson number from 26 to 31 August 2009. Notice the different kinds of evening transitions.

Figure 4: Evolution of the TKE along the transition times studied (17-23 UTC) for different kinds of transitions.



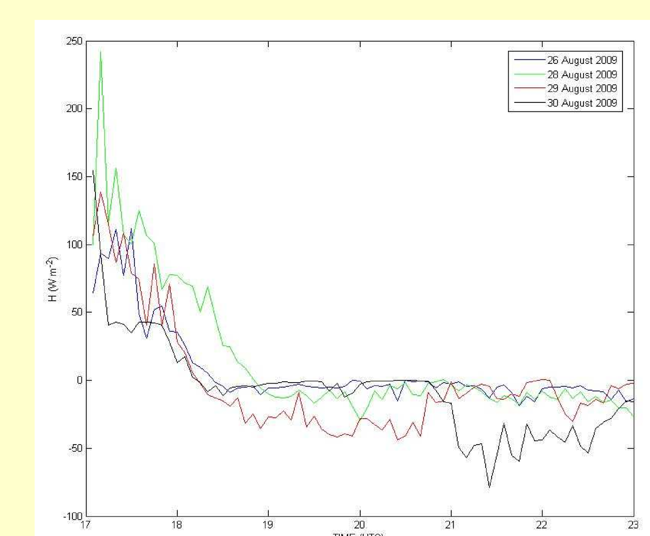


Figure 5: Evolution of the Sensible Heat Flux along the transition times studied (17-23 UTC) for different kinds of transitions.

APPENDIX I: Stability and Turbulent parameters

Bulk Richardson Number:

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

$\Delta\theta=\theta_{10}-\theta_{1.5}$. $\Delta U=U_{10}-U_{1.5}$.

U is the wind speed and θ the potential temperature.

Z_1=1.5m; Z_2=10m

Temperature difference:

$$\Delta T_{10-1.5} = T_{10\,m} - T_{1.5\,m}$$

Turbulent Kinetic Energy:

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

Friction Velocity:

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

5. ACKNOWLEDGMENTS

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