Study of the interaction between fog and turbulence

C. Román-Cascón(1), F. Salamanca(1,2), C. Yagüe(1) , G. Maqueda (3) and S. Viana(4)

(1) Dept. de Geofísica y Meteorología. Universidad Complutense de Madrid, Spain. (carlosromancascon@fis.ucm.es); (2) CIEMAT, Madrid, Spain. (3) Dept. de Astrofísica y Ciencias de la Atmósfera. Universidad Complutense de Madrid, Spain. (4) AEMET, Barcelona, Spain

1. INTRODUCTION

- The **adverse effects** of **fogs** on human life are clearly visible, especially on transport in its different ways: air, maritime and terrestrial; however, a **well forecasting** of fog is one of the goals still **not achieved** by the operational meteorological services. The **physical processes involved** in the evolution of fogs are **not well understood**, and therefore, **not well parameterized** in the weather forecasting models [1,2] .In particular, the **role of the turbulence** over the formation and dissipation of fogs is one of the most interesting features to study. While some authors establish that turbulence is a factor inhibiting the formation of fog [3], other found the opposite, i.e. turbulence acts favoring the formation of fog [4]. Maybe, a combination of both theories leads to the conclusion that there exists a **threshold on the relation between turbulence and fog** [5].

- This work is a preliminary investigation studying **the relation between turbulence and fog** (visibility < 1 km) from a detailed **analysis** of different observational **data**. **WRF-ARW**[6] v3.2.1 model is also used to see how a very high resolution NWP model **simulates the fog.**

- The poster is divided into 3 sections: STATISTICAL ANALYSIS – CASE STUDY OBSERVATIONAL ANALYSIS – CASE STUDY WRF SIMULATION.

2. SITE AND DATA

- Data is taken from two meteorological towers (10 and 100 m) located at CIBA (Research Centre for the Lower Atmosphere), near Valladolid, Spain, placed on a fairly homogeneous terrain in the centre of an extensive plateau (41º49´N, 4º 56’ W, 840 m asl). Also METAR visibility information is used, coming from Villanubla Airport, which is placed around 13 km in the SE direction from CIBA. (See poster XY584, this session, for site characteristics)

3. STATISTICAL ANALYSIS

- A statistical analysis of meteorological parameters (including turbulent parameters) is done with more than 100 hours of fog (visibility < 1 km) with the goal of drawing the most appropriate conditions for fog events.

- A large amount of meteorological data during several **radiation fog** episodes (20 days in 4 different winter months of 2009 and 2010) over CIBA are statistically analyzed. The magnitudes analyzed are: **wind speed, Bulk Richardson number, particles (r<1 µm) concentration (PM1) , mixing ratio, temperature difference (T_{10}-$T_{1.5}$), friction velocity, turbulent kinetic energy and sensible heat flux.** 5 minutes means have been used.

- The analysis is done **without data of formation/disipation** of fog, where the values of the magnitudes can significantly change. Anyway, some data (outliers) can come from these hours, because of the possibly not agreement between CIBA and Villanubla airport (separated 13 km).

- Figure 1 shows:
  - **Histograms** showing the relative frequency of the different values on the dataset.
  - **Boxplots** displaying the dataset (minimum, lower quartile, median, upper quartile and maximum). It also indicates which observations can be considered outliers and it is useful to see the degree of dispersion and skewness in the data.

- Table 1 is a **summary** of different statistical values for each meteorological parameter.

	1.5 m Wind speed (m/s)	T_{10}-$T_{1.5}$ (º C)	Bulk Richardson number	10 m Mixing ratio (g/kg)	10 m Sensible heat flux (W/m²)	10 m TKE (m²/s²)	10 m Friction velocity (m/s)	2 m PM1(µg/m³)
Number of data	1065	1066	952	1066	1045	1058	1058	942
Mean	1.05	-0.23	-0.27	1.76	16.30	0.171	0.200	9.35
Standard deviation	0.63	0.72	0.79	1.17	31.82	0.097	0.205	5.90
Minimum value	0.007	-1.80	-2.97	0.49	- 40.84	0.011	0.005	0.87
Maximum value	3.64	2.69	3.75	11.91	248.08	0.555	1.319	29.40
Median	0.92	-0.26	-0.06	1.38	3.01	0.153	0.131	8.51
Inferior quartile	0.59	-0.61	-0.51	1.10	-2.03	0.099	0.066	4.47
Superior quartile	1.36	-0.12	0.008	1.98	25.52	0.226	0.243	13.45

Table 1. Statistical values.

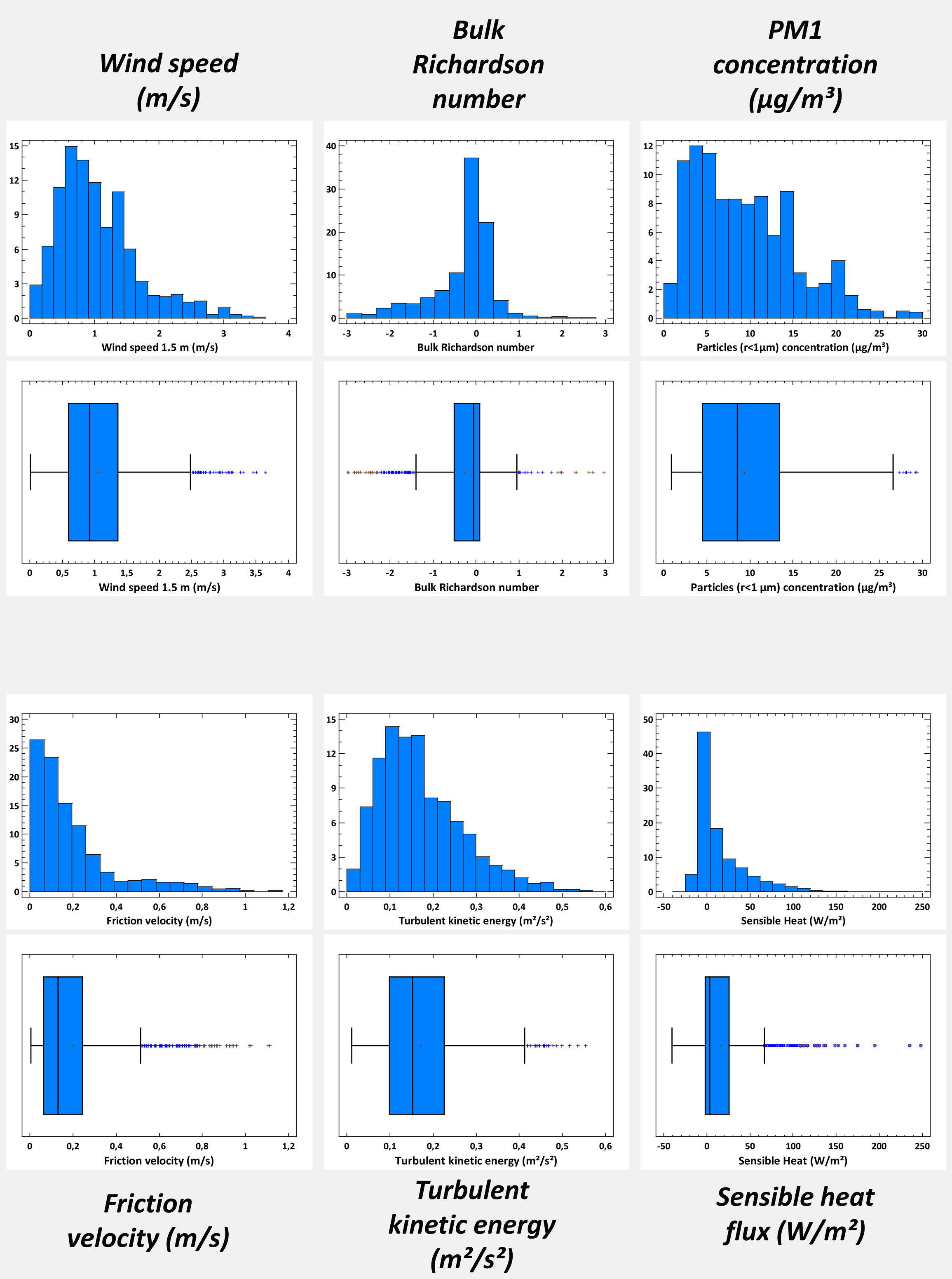

Figure 1. Relative frequency histograms and boxplots.

4a. CASE STUDY OBSERVATIONAL ANALYSIS

- 4-5-6 November 2010 period is deeply analyzed using data from instruments located at **CIBA**. Also METAR visibility information at **Villanubla airport** is used.

- The **synoptic situation** was dominated by a **high pressure system** with **weak pressure gradient**, light winds and surface cooling during the nights, i.e. **favorable conditions** for radiation fogs (figure 2).
- Figure 3 shows visibility (no data from 22.00 to 05.00 UTC is available), temperature difference between 10 m and 1.5 m, bulk Richardson number and particles concentration for the studied period. Table 2 shows differences between the fogs of the studied days.

- NOTES - Stars denote fogs (visibility < 1 km) and points denote mists (1 km < visibility < 5 km) for figures.
- Sunrise and sunset at CIBA for the studied period: 06.55 UTC and 17.05 UTC respectively.

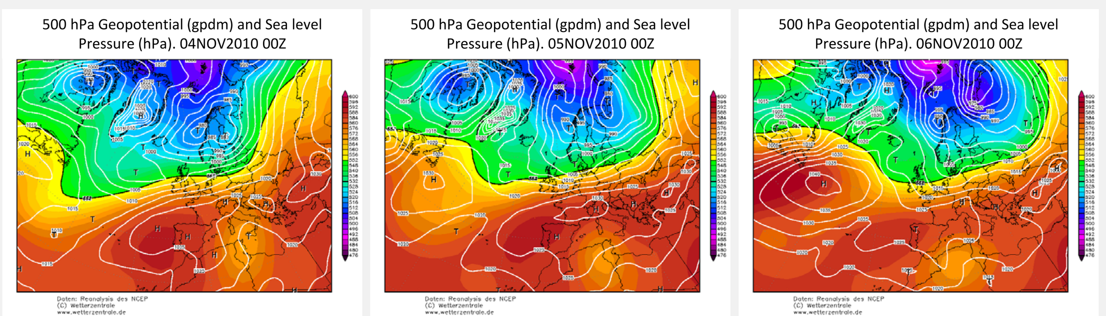

Figure 2. Synoptic situation for November 4th, 5th and 6th (from left to right).

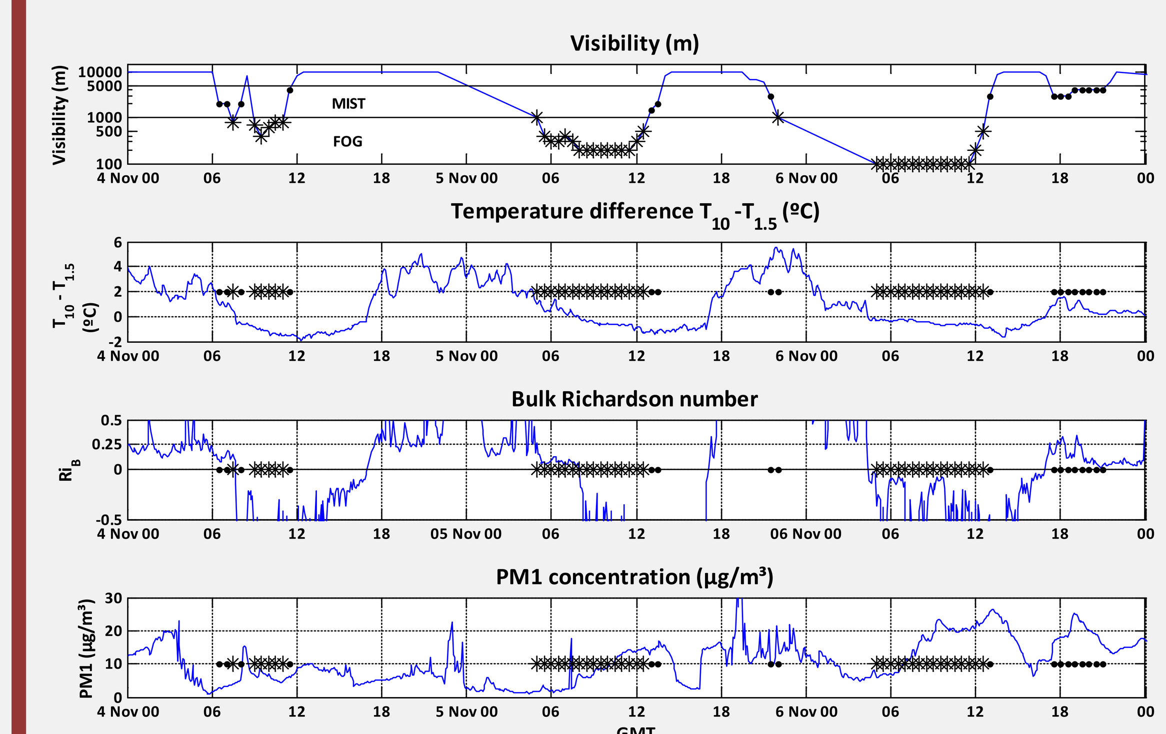

Figure 3. OBSERVATIONS - Visibility, T_{10}-$T_{1.5}$, Bulk Richardson number and PM1 concentration.

Day	Fog type	Time interval	Visibility	Relative humidity at 97 m	Mean particles concentration
04-nov	Patchy fog	09.00-11.00	700 m	80-90 %	6.08 µg/m³
05-nov	Fog	05.00-12.00	200 - 300 m	>90% from 09.00 to 12.30	7.58 µg/m³
06-nov	Dense fog	04.00*-12.30	100 m	>90% from 06.00 to 13.00	16.37 µg/m³

Table 2. Fogs features (* inferred from temperature profile)

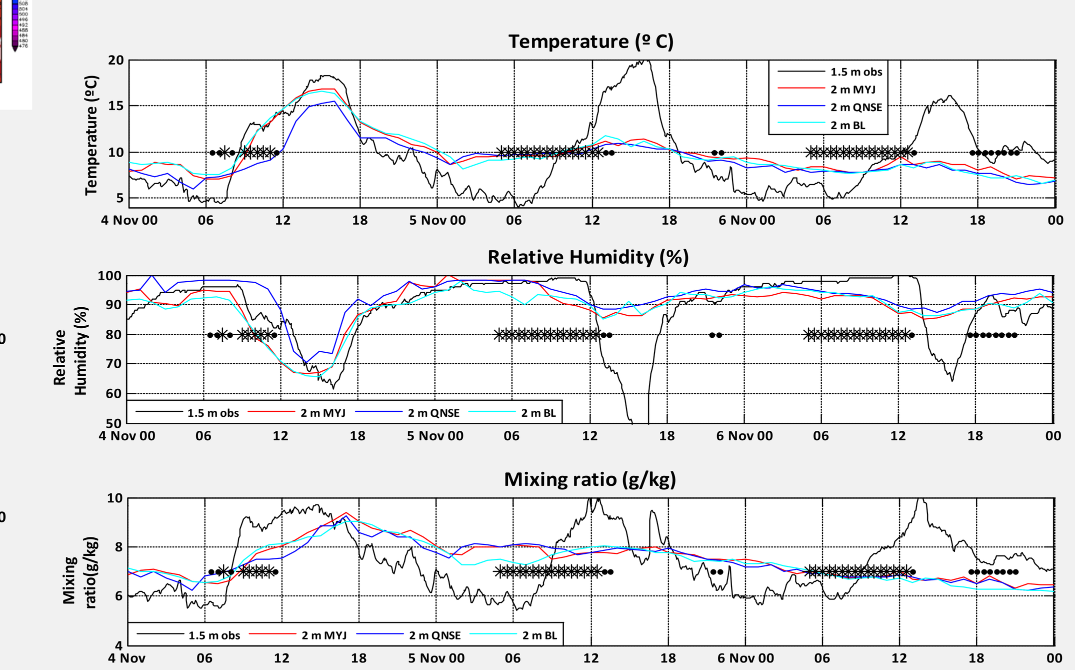

Figure 4. SIMULATIONS Vs OBSERVATIONS – Temperature, relative humidity and mixing ratio

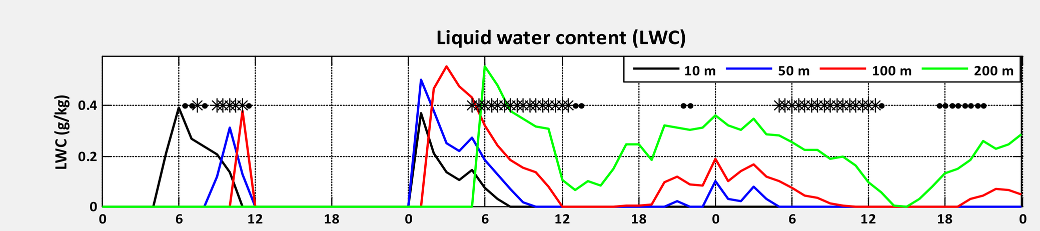

Figure 6. LWC simulation at different heights for QNSE scheme.

4b. CASE STUDY WRF SIMULATION

- **WRF results** are **evaluated** with observations to **determinate the ability of the model** to forecast a radiation fog. 3 different **PBL parameterizations schemes** are used in order to determinate which one is better to use in this case of radiation fog:
  - **MYJ** – Mellor-Yamada-Janjic (Eta) TKE scheme [7]
  - **QNSE** – Quasi Normal Scale Elimination scheme [8]
  - **BL** – Bougeault and Lacarrere (BouLac) TKE scheme [9]

- Table 3 shows more details of the simulations.

- Figures 4 and 5 are **comparisons** between **observations** and **model results** of several parameters (temperature, relative humidity, mixing ratio, friction velocity, sensible heat flux and incoming short wave radiation) for the different PBL parameterizations used.

- Figure 6 shows **liquid water content (LWC) (g/kg)** at different heights for QNSE scheme and figure 7 represents vertical profiles of LWC at different hours for the different PBL schemes used in the simulation.

Horizontal domains	Grid points	Grid spacing	Initial and boundary conditions	Vertical resolution	SW radiation scheme	LW radiation scheme	Microphysics package
4 two-way nested domains	100x100 120x120 120x120 120x120	27, 9, 3, 1 km	National Centre for Environmental Prediction (NCEP). Grid and time resolution = 1º x 1º, 6 hours	51 eta levels (33 in the lowest 1.5 km) Domain top over 20 km	Dudhia (1998)	RRTM	WSM3

Table 3. Simulation features.

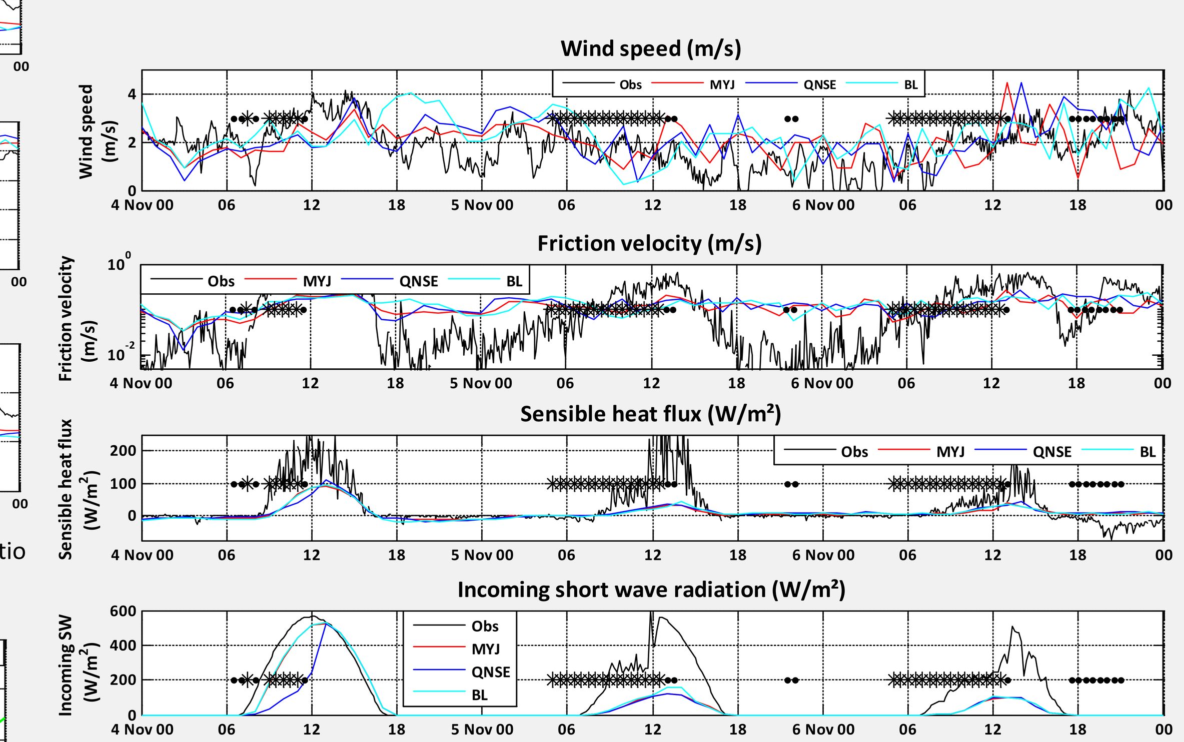

Figure 5. SIMULATIONS Vs OBSERVATIONS – Wind speed at 10 m, friction velocity, sensible heat flux and incoming SW radiation

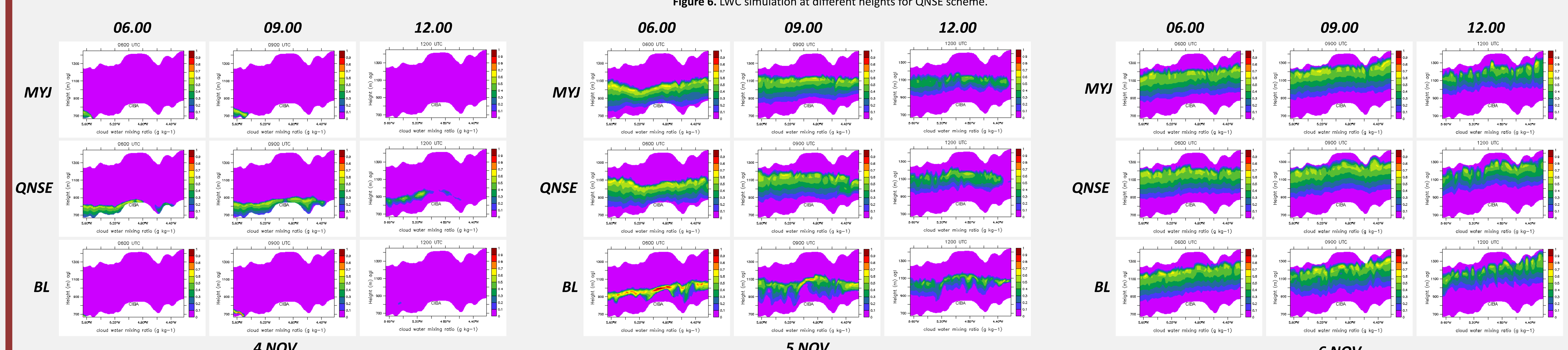

Figure 7. Vertical LWC (g/kg) for November 4th, 5th,6th (from left to right), for the different WRF turbulent schemes used (MYJ, QNSE, BL from up to down) at 06.00, 09.00 and 12.00 hours (from left to right for each day)

5. DISCUSSION AND CONCLUSIONS

- STATISTICAL ANALYSIS

- Radiation fogs usually occur with some degree of turbulence, probably after a strong inversion. The **fog** seems to **develop** when **turbulence starts increasing** (see statistics for TKE, u*, H and Ri_B).

- CASE STUDY OBSERVATIONAL ANALYSIS

- Fogs were **preceded** by intense thermal **inversions** (stable pbl) during nights caused by the synoptic situation, and their **formation** ocurred with the **decrease** in $\mathbf{Ri_B}$ below subcritical values (<0.25), indicating a more intense turbulence. This would imply that **fog needs some turbulence to its vertical development**, but when it increase **much more**, it causes the fog **dissipation**.
- With similar conditions, **particles concentration** seems to be an **important factor** controlling the fog density (visibility).

- CASE STUDY WRF SIMULATION

DAY 4 – The model did not capture well the fog (patchy fog), except for **QNSE** scheme, where the model captured well the fog formation and dissipation over CIBA (but 2 or 3 hours anticipated).
DAY 5 – QNSE and MYJ schemes captured well the fog, followed by a **posterior transformation into low clouds**, with the consequent absorption of short wave radiation (not permitting the temperature to increase during the day as in the reality).
DAY 6 – It was the day with more intense and more extensive fog in the vertical, however **all the schemes simulated low clouds** instead of fog, not capturing well other meteorological parameters because of the influence in the radiation scheme.

- **QNSE** seems to be the **best WRF PBL scheme** used for fog detection in this experiment, however, the fogs were not well predicted every day, the model **anticipated the fog formation** and it transformed the fog in dense **low clouds that did not exist** in the reality at all. **Further research** is **needed** with more case studies.

6. ACKNOWLEDGMENTS

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