A case study of shallow radiation fogs over CIBA: Observations and simulations (WRF and HARMONIE models)

C. Román-Cascón(1) (carlosromancascon@fis.ucm.es), G. Morales(2), C. Yagüe(1), M. Sastre(1), G. Maqueda(3) and J. Calvo(2)

(1) Departamento de Geofísica y Meteorología. Universidad Complutense de Madrid, Spain. (2) AEMET. (3) Departamento de Astrofísica y Ciencias de la Atmósfera. Universidad Complutense de Madrid, Spain.

1. INTRODUCTION

- Despite the well-known adverse effects of fogs over human life, its forecasting is one of the goals still not well achieved by the Numerical Weather Prediction (NWP) models. One of the reasons is because there coexist many processes acting together and affecting the fog cycle, being difficult to correctly parameterize them [1], [2]. At CIBA site (Spain) [3], on January 2012 there was a period (3rd-15th) characterized by high pressure systems over the western of Europe, and it led to more than 10 consecutive foggy days with different features (thickness, persistence during the daytime, vertical extension, freezing temperature values…). Two of these days (characterized by strong surface-based thermal inversions with shallow fogs) have been chosen due to the previously checked special difficulty of models simulating this type of radiation fogs.

- A deep observational data analysis from CIBA (Research Centre for the Lower Atmosphere) has been carried out. This centre is located in the Montes Torozos (41º 47'N, 4º 56'W , 840 m asl), an extensive and homogeneous plateau situated over the Spanish Northern Plateau. This place is specially suitable for the development of radiation fogs during autumn and winter. METAR data from the nearly Villanubla airport (15 km SSE from CIBA) has also been used to support the existence of fogs over the zone. This airport is specially affected by fogs during winter and in fact, Villanubla means *"foggy town"* in Spanish. It is important to note the special hazard of shallow fogs over landing/take off maneuvers.

- Weather Research and Forecasting (WRF) [4] and HARMONIE [5], [6] model outputs has been compared to CIBA observations in order to check the ability of these models simulating these shallow fogs. They have been also compared to low clouds from Meteosat (MSG v2012.2) satellite data product (SAF NWC of EUMETSAT) to compare the simulated and observed spatial distribution of fogs.

- As the formation of radiation fogs starts from surface, it is important to test the use of different land-surface schemes available in WRF ARW 3.4.1 model, including several combinations of options available with the Noah multi-physics [7], [8] land-surface scheme, a new implementation in this latest version of WRF. The effect of using MODIS land use dataset instead of the default USGS data set have also been checked. With these preliminary experiments, the authors try to determine the importance of land-atmosphere processes and vegetation over shallow radiation fogs, supposed to be strongly affected by the surface.

2. MODELS SETUP

HARMONIE System in AROME configuration[5], [6]

- **Horizontal domains –** 1 domain
- **Grid –** 2.5 km
- **Boundary conditions –** Forecast ECMWF, 16km
- **Vertical resolution** 65 levels "eta" (5 levels< 100 m) (21 levels< 1 km)
- **Time step** - 60 s
- **PBL scheme -** 1D prognostic Cuxart-Bougeault TKE [9]
- **Microphysics scheme -** ICE3 package [10]
- **Radiation scheme -** Mocrette scheme [11]
- **Land-surface -** SURFEX scheme [12]

WRF ARW 3.4.1 general configuration

- **Horizontal domains -** 4 nested domains
- **Grid -** 27, 9, 3, 1 km
- **Boundary conditions -** NCEP, 1º, 6 hours
- **Vertical resolution** 50 levels "eta" (8 levels< 100 m) (28 levels< 1 km)
- **Time step** - 81 s
- **Spin up** - 24 h
- **PBL scheme -** QNSE [13]
- **Surface layer scheme** – QNSE
- **Microphysics scheme –** Lin et al. [14]
- **SW radiation**- RRTMG
- **LW radiation** – RRTMG

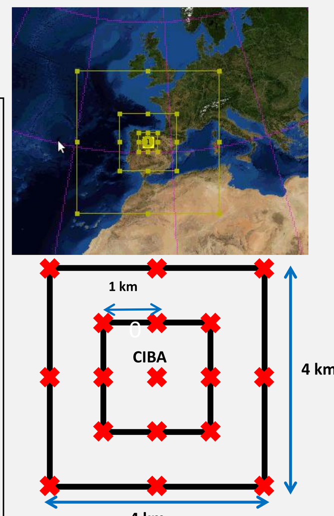

Figure 1. Simulations setup (HARMONIE, left box; WRF, right box) and map with the 4 nested domains of WRF centered at CIBA site. The fourth figure shows the 17 points used to average the simulated values of the different parameters (temperature, LWC, relative humidity…), i.e. 17 points have been used and not only one point. The same have been done with HARMONIE but with 4 points, with an spatial coverage of 2.5km x 2.5km.

WRF ARW 3.4.1 specific experiments configuration

- **WRF-Noah ->** Noah land-surface scheme [15]
- **WRF-RUC ->** RUC land-surface scheme [16]
- **WRF-MP1 ->** Noah Multi-physics [7], [8] land surface-scheme. Dynamic vegetation option ON
- **WRF-MP2 ->** Noah Multi-physics land surface-scheme. Dynamic vegetation option OFF (LAI from table; FVEG= max. vegetation fraction)
- **WRF-MP3 ->** Same as WRF-MP2 but with stomata resistance option=Jarvis
- **WRF-MP4 ->** Same as WRF-MP3 but with less permeable soil (non-linear effect)
- **WRF-MP2-MODIS ->** Same as WRF-MP2 but with MODIS land-use dataset instead of USGS

Figure 2. Specific WRF experiments configuration used for this study.

3. OBSERVATIONAL DATA ANALYSIS

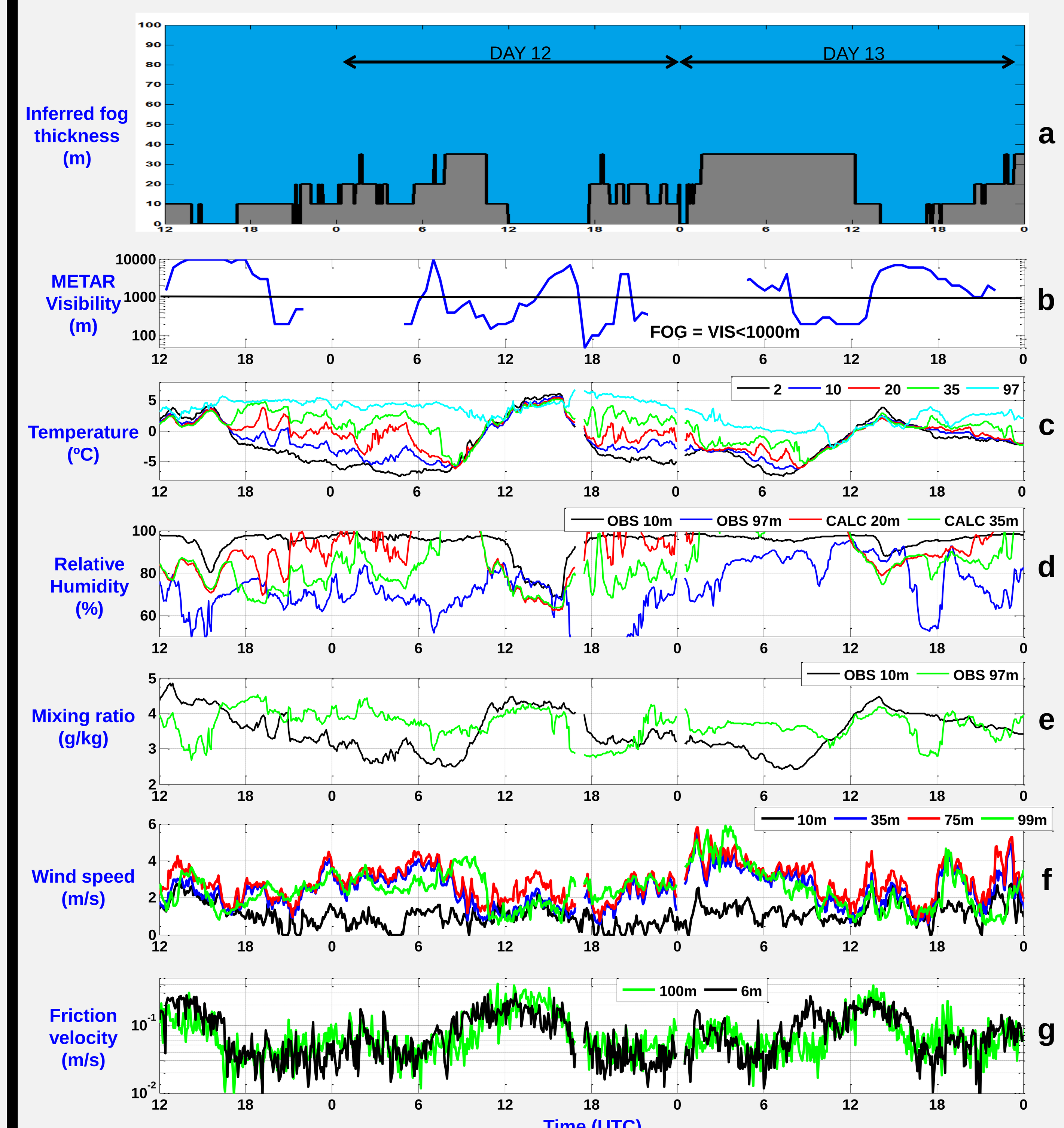

Figure 3. OBSERVATIONAL ANALYSIS. a) Inferred fog thickness (m) (fog considered if relative humidity > 95% at specific levels). b) Visibility information (m) from METAR reports at Villanubla airport (15km SSE from CIBA). c) Temperature (ºC). d) Relative humidity (%) (NOTE: relative humidity at 20m and 35m calculated from temperature and a fixed mixing ratio of 3.8 g/kg (approximation). e) Mixing ratio (g/kg). f) Wind speed (m/s). g) Friction velocity (m/s) from sonic anemometers.

- **STRONG surface based thermal inversions (even 12º between 2m and 97m)**
- **Lower layers -> Lower temperatures -> Higher relative humidity -> FOG**
- **Higher layers-> Higher temperatures -> Lower relative humidity -> NO FOG**
- **Low values of friction velocity -> no surface cooling extended to higher levels -> no vertical extension of fogs**

} SHALLOW FOGS

- **Small changes in friction velocity -> control vertical extension of fog (20-35m).**
- **Solar radiation (not shown) able to reach the ground due to shallow condition of fogs, increase friction velocity and destabilize the PBL from sunrise (no increase in wind speed).**
- **Mixing ration at lower layers mainly controlled by condensation/evaporation (formation/dissipation of fogs).**
- **Mixing ratio at higher layers mainly controlled by turbulent mixing.**
- **LLJ during nights and even during days (fogs can modified diurnal PBL)**

4. SIMULATIONS AT CIBA (LWC: LIQUID WATER CONTENT)

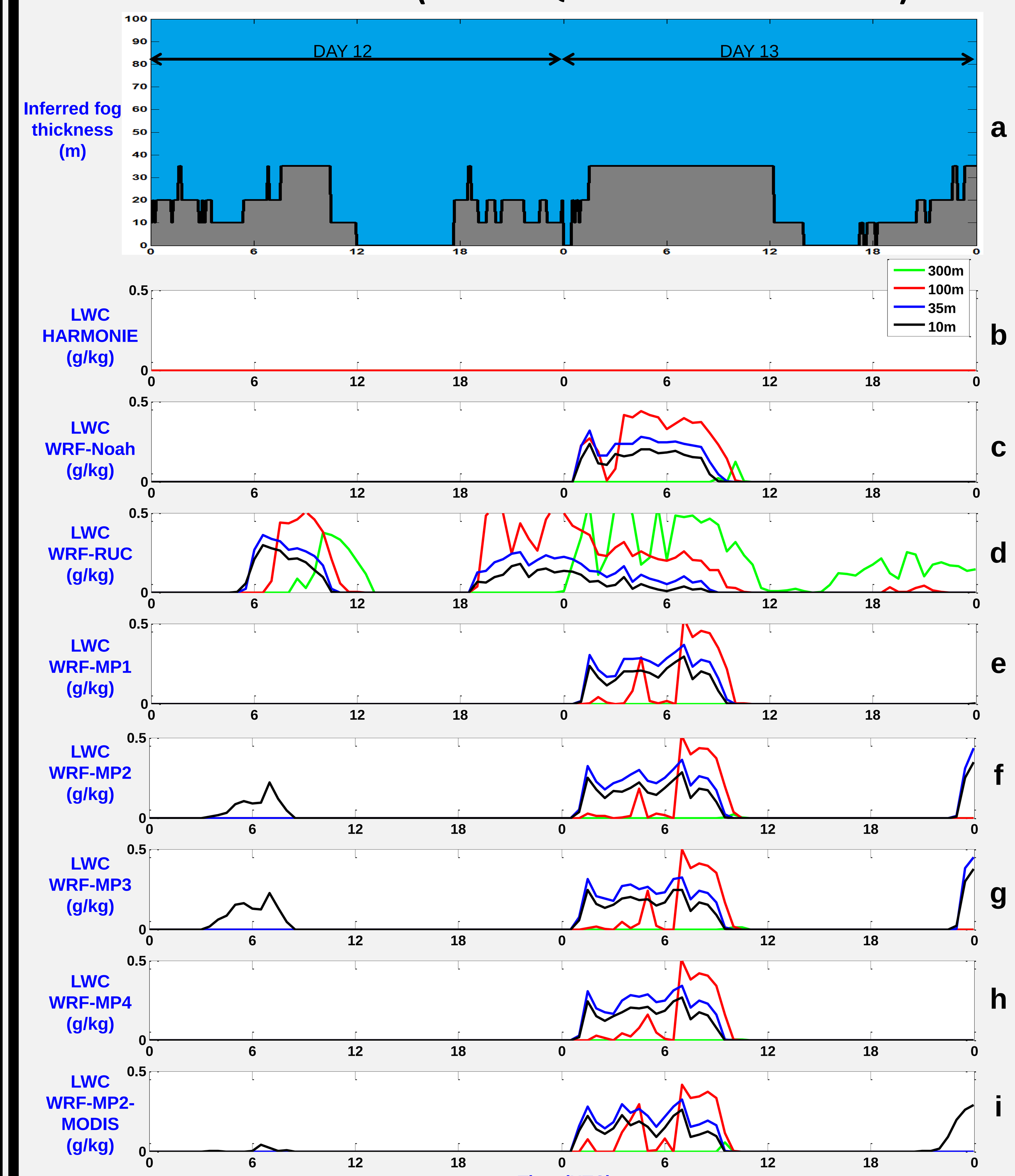

Figure 4. LWC simulations at CIBA. a) Inferred fog thickness (m). Rest) LWC simulated by HARMONIE (b), WRF-Noah (c), WRF-RUC (d), WRF-MP1 (e), WRF-MP2 (f), WRF-MP3 (g), WRF-MP4 (h) and WRF-MP2-MODIS at 10m (black), 35m (blue), 100m (red) and 300m (green). **NOTE ->** For a better description of simulations, see Section 2 (Models setup).

- **HARMONIE does not simulate the fog during the studied period.**
- **WRF:**
  - **In general, this WRF configuration simulates fog for day 13 but not for day 12**
  - **RUC land surface scheme simulates fog for day 12 and it is better for day 13 , although it tends to overestimate the vertical extension. The fog is simulated due to a higher and incorrect simulation of mixing ratio (see Sect. 4)**
  - **WRF-MP2 (max vegetation fraction option with Noah Multi-physics land surface scheme) introduces improvements for day 12**
  - **WRF-MP4 (less soil permeability option) shows worse results**
  - **WRF-MP2 with MODIS land use dataset also gets worse for day 12**

5. SIMULATIONS AT CIBA (OTHER RELATED VARIABLES)

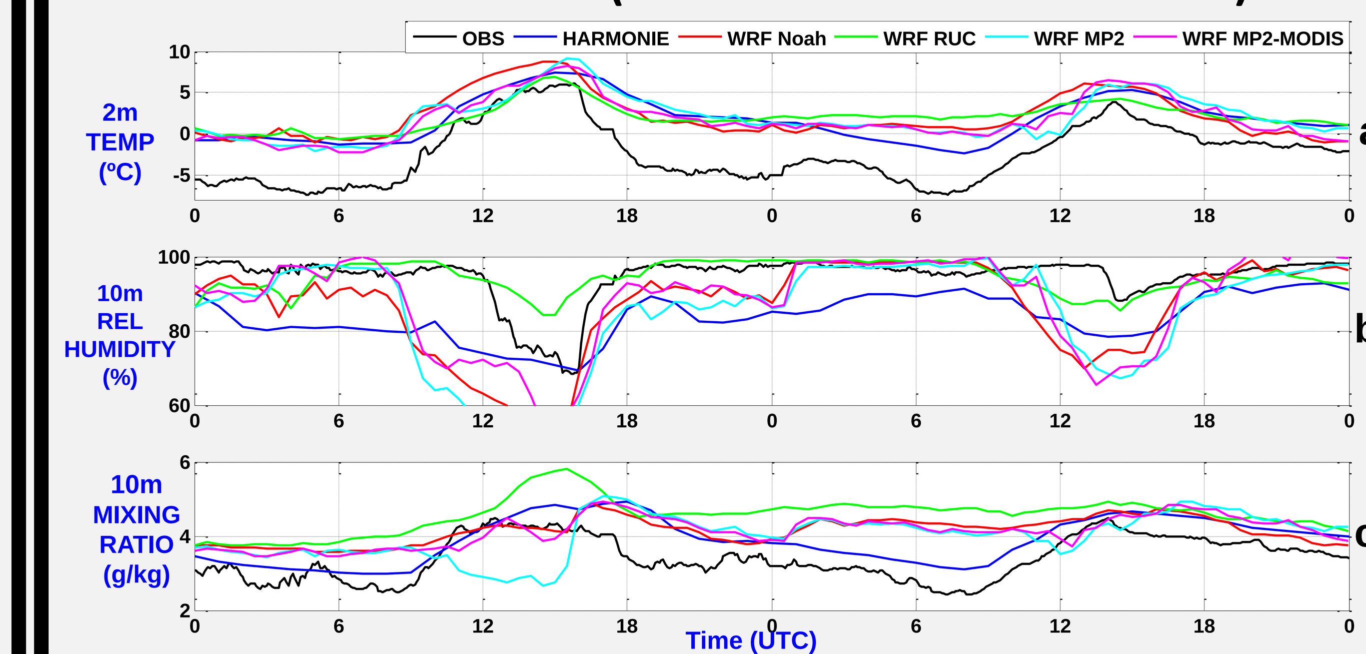

Figure 5. Simulations at CIBA. a) 2m temperature (ºC). b) 10m relative humidity (%). c) 10m mixing ratio (g/kg)

	T (fog) (ºC)	T (no fog) (ºC)	RH (fog) (%)	RH (no fog) (%)	r (fog) (g/kg)	r (no fog) (g/kg)	WS (fog) (m/s)	WS (no fog) (m/s)	U* (fog) (m/s)	U* (no fog) (m/s)
HARMONIE	4,53	3,08	-11,06	-10,65	0.48	0.45				
WRF-Noah	4,87	3,48	-5,86	-15,06	0,85	0,34	0,82	0,55	0,08	0,05
WRF-RUC	5,29	1,76	-1,53	3,90	1,19	0,96	0,78	0,74	0,11	0,10
WRF-MP1	4,81	2,98	-11,21	-24,04	0,60	-0,33	0,90	0,48	0,09	0,08
WRF-MP2	4,82	3,22	-6,15	-22,73	0,83	-0,18	0,86	0,39	0,10	0,08
WRF-MP3	4,88	3,15	-6,16	-22,54	0,85	-0,18	0,90	0,37	0,10	0,08
WRF-MP4	4,80	2,85	-11,06	-23,46	0,61	-0,32	0,90	0,38	0,09	0,08
WRF-MP2-MODIS	4,50	3,12	-3,66	-14,55	0,84	0,28	1,04	1,29	0,07	0,05

Table 1. BIAS. [Simulated values – Observed values] for 2m temperature, 10m relative humidity, 10m mixing ratio, 10m wind speed and friction velocity near surface; separately for fog moments and non-fog moments.

- **2m temperature is overestimated by all, specially during night and fog moments.**
  - **Consequently, 10m relative humidity is underestimated.**
    - **No correct simulations of fogs.**
- **WRF overestimates mixing ratio (r), specially WRF-RUC.**
  - **WRF-RUC simulates the fog due to a overestimation of mixing ratio.**
- **Better BIAS for 10m mixing ratio and 2m temperature for HARMONIE.**
- **Better BIAS values during non-fog moments.**

6. SPATIAL COMPARISON WITH SAF NWC (EUMETSAT). FUTURE WORK!

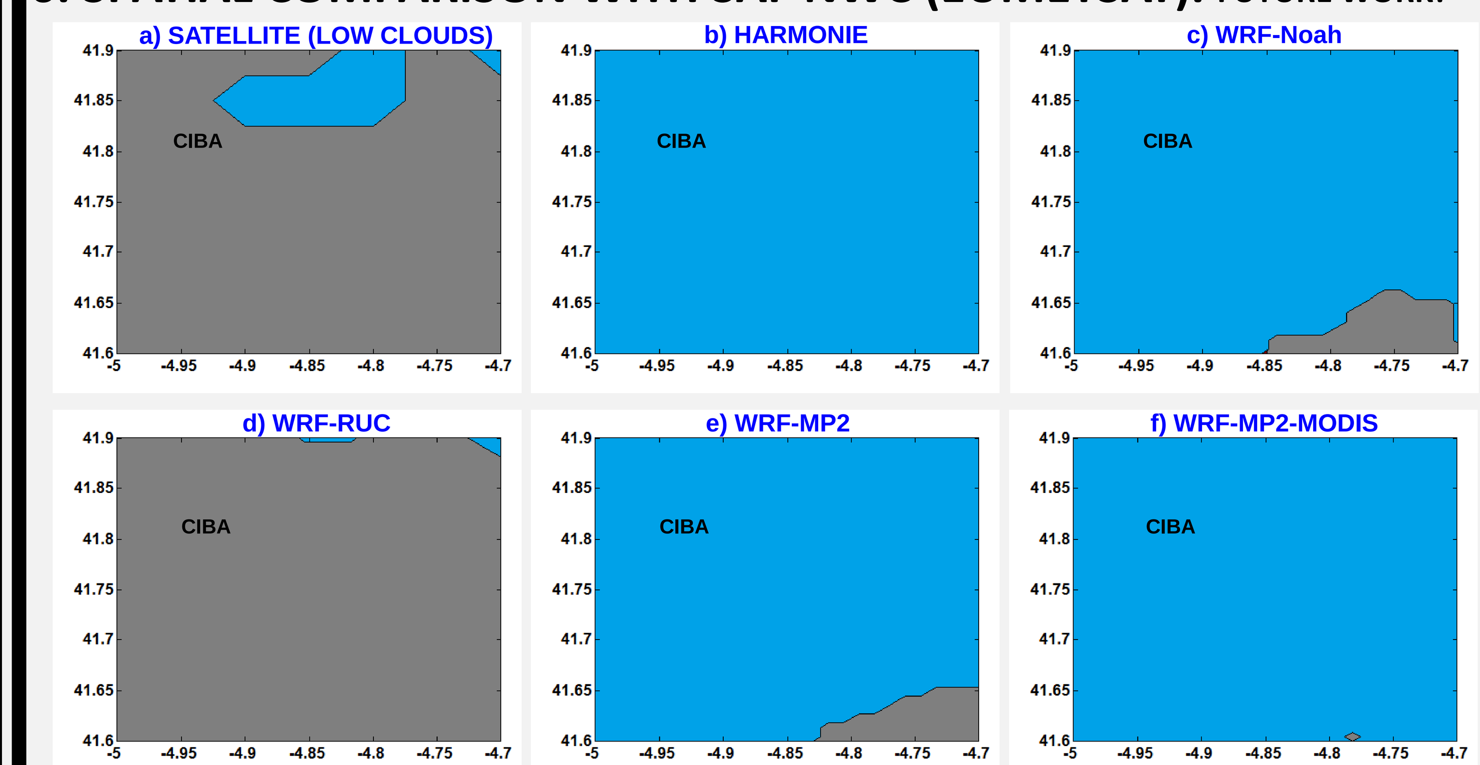

Figure 6. EXAMPLE OF LOW CLOUDS/FOGS OBSERVATION AND SIMULATIONS. a) Low clouds from SAF NWC for day 12 at 11:00 UTC. Rest) Simulation of low clouds (from LWC at layers <300m) by HARMONIE (b), WRF-Noah (c), WRF-RUC (d), WRF-MP2 (e) and WRF-MP2-MODIS (f) for day 12 at 11:00 UTC. Note -> The shown region covers an extension of 30km x 30km approximately.

- **SAF NWC from EUMETSAT -> good tool to perform spatial comparisons with model.**
- **The relative importance of land use and soil type can be checked for these shallow fogs, as well as local influences.**
- **Use of SAL method to obtain statistical information of ability of models simulating the fogs spatially (see next poster B707 (EGU2013-8474), Morales et al.).**
- **SAF NWC uncertainties -> definition of low clouds as clouds < 4000m. It is important to check the inexistence of other low clouds (only fogs) before comparing. For this purpose, see animation of satellite, LW radiation, METAR reports…**

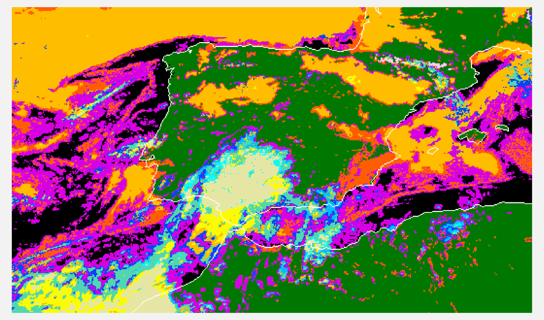

Figure 7. Iberian peninsula SAF NWC for day 12 at 11:00 UTC. Light orange indicates "very low clouds". With several satellite images like this one, it can be checked if the low clouds are moving of if they are stationary over a zone in time (radiation fogs) . In this case, fogs are observed in the Northern Spanish Plateau (CIBA site) and over the Ebro basin.

7. CONCLUSIONS

- **STRONG SURFACE COOLING + LOW TURBULENCE -> STRONG THERMAL INVERSIONS -> SHALLOW FOGS (10m-35m)**
- **DIFFICULT SIMULATION OF SHALLOW FOGS (models markedly overestimate nocturnal 2m temperature -> Underestimation of relative humidity -> No prediction of fogs)**

- **The use of RUC land surface scheme in WRF obtained best results in LWC BUT through a WRONG overestimation of mixing ratio**
- **LWC amounts at 10m seems to be slightly sensible to changes in land surface processes (Noah Multi-physics) and to land use data-set.**

- **FUTURE WORK – 1. More experiments focusing in combinations of turbulence and land-surface parameterizations. 2. SAL statistics for spatial comparisons**

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