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THE PERFORMANCE OF THE WRF-ARW MODEL OVER CATALONIA (NE-SPAIN) WITH DIFFERENT CONVECTIVE AND MICROPHYSICAL PARAMETERIZATIONS

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1. INTRODUCTION

The performance of the WRF-ARW v2.2 model (Skamarock et al., 2005) has recently been evaluated over Catalonia in order to study the feasibility of being implemented operationally in the Meteorological Service of Catalonia (SMC).

Because of the importance of precipitation forecasts in this area, the main objective was to assess the model sensitivity to several configurations of convective and microphysical parameterizations, in order to find a stable configuration.

In this work, the results from the forecasts verification of simulations over a 36-km domain and its nested 12-km domain are discussed, paying special attention to quantitative precipitation forecasts (QPF). Previously, the selected events and data used to verify the forecasts are presented, as well as the model configuration and the verification methodology.

2. DATA DESCRIPTION

2.1. The selected events

11 CASE STUDIES	43 INITIALIZATION TIMES	602 SIMULATIONS
• Between 15th June, 2006 and 16th March, 2007. • Observed convective or stratiform rainfall over Catalonia.	• 00 UTC : 23 times • 12 UTC : 20 times	• 258 (344) for the 36 (12)-km domain • 6 (8) configurations for the coarser (inner) domain resulting from the combination of two microphysical schemes and 3 (4) cumulus parameterizations

2.2. Observational data for verification

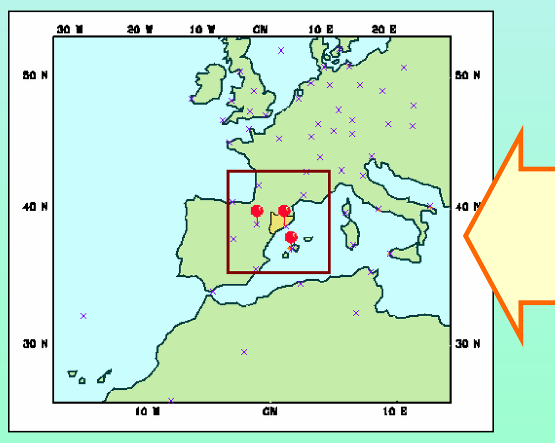


Figure 1. The coarse and inner domains (the latter within the red square) with location of radiosounding stations in violet crosses and the 3 upper-air stations used to verify the inner domain forecasts marked by balloons (from left to right: Zaragoza, Barcelona and Palma). In yellow, the location of Catalonia.

1. GFS Analysis 1º (GFS-ANL)

Data to generate the WRF analyses.

2. RADIOSOUNDING data

Upper observations from all the radio-sounding stations within the domain are used both to improve the WRF analyses and to be directly compared to forecasts.

3. METAR data

To improve the WRF analyses.

4. RAIN –GAUGES observations

From the high-density SMC stations network (about 300 in total).

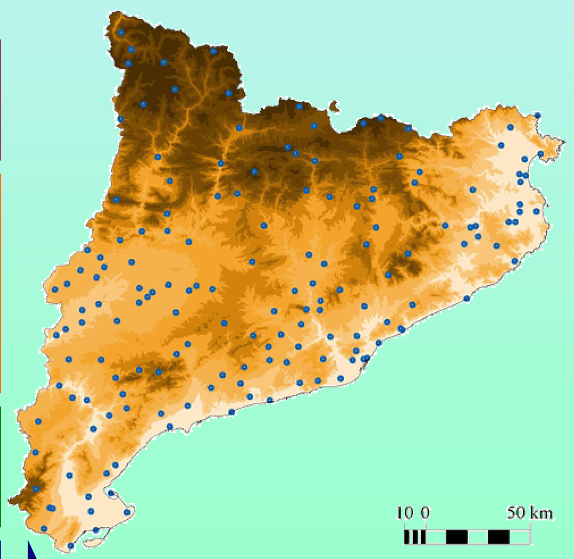


Figure 2. Map of Catalonia (in yellow in Figure 1) with the rain-gauges stations belonging to the high-density SMC network in blue dots.

3. MODEL CONFIGURATION

Both domains (Figure 1) are defined as those currently being used for operational forecasts in SMC (SMC, 2007).

The model configuration is shown in Table 2.

PHYSICAL OPTIONS

- **FIXED schemes:** Kept without change through all the simulations.
- **TESTED schemes:** Have been combined leading to 6 possible combinations of different physical schemes for the coarser domain and 8 available configurations for the inner one.

DOMAIN (grid points)	INITIAL CONDITIONS	LBC	Time step	Fixed schemes	Tested schemes	Possible configurations
36 – km (94 x 102 x 31)	**FIRST GUESS** - GFS 1º, +12h forecast. - Initialized 12 h before. **DATA ASSIMILATION** - Conventional surface + upper data. - By the WRF-3DVAR *(Barker, et al. 2004).*	**GFS 1º** - 6-hourly forecasts. - Initialized 12h before.	**216** s	**LSM:** NOAH (4 subsoil layers) **PBL:** YSU **Surface layer:** Monin-Obukhov **SW radiation:** Dudhia **LW radiation:** RRTM	**CUMULUS:** KF : Kain-Fritsch BMJ : Betts-Miller-Janjic GD : Grell-Devenyi **MICROPHYSICS:** WSM5 Thompson	**KF.WSM5**, **KF.Thom** **BMJ.WSM5**, **BMJ.Thom** **GD.WSM5**, **GD.Thom**
12 – km (70 x 70 x 31)		**SIMULTANEOUS ONE-WAY NESTING** - Every coarse domain time step.	**72** s		**CUMULUS:** KF BMJ GD EXP : Explicitly resolved **MICROPHYSICS:** WSM5 and Thompson	**KF.WSM5**, **KF.Thom** **BMJ.WSM5**, **BMJ.Thom** **GD.WSM5**, **GD.Thom** **EXP.WSM5**, **EXP.Thom**

4. VERIFICATION METHODOLOGY

The verification has been done following three different ways:

1. GRID to GRID → **Forecasted field ⇅ Analysis field**

Analysis generated by the WRF model combining data from GFS-ANL and conventional observations (METAR and upper-air observations) assimilated by the 3D-VAR.

2. POINT to POINT → **Forecasted radiosounding ⇅ Observed radiosounding**

The forecasted radiosounding is computed at the nearest neighbor grid-point of each radiosounding point (avoiding horizontal interpolation), only in standard vertical levels (1000, 925, 850, 700, 500, 400 and 300 hPa).

Computed indexes: ME, RMSE, MVWE

Evaluated variables: Temperature, Relative Humidity, Geopot. Height (Z), Wind

3. QPF Verification → **Forecasted field ⇅ Analysis field**

Rainfall observations are analyzed over a 32x24 grid over Catalonia where the forecasted field is also interpolated to. ⇒ The both fields are masked to compare only the area within Catalonia boundaries

CONTINGENCY TABLE ⇒ POD, FAR, CSI scores

5. RESULTS

5.1. Grid to grid: 36-km domain

Some results are shown in this table:

	LEV (hPa)	KF. WSM5	KF. Thom	BMJ. WSM5	BMJ. Thom	GD. WSM5	GD. Thom
T (ºC)	850	**-0.18 (1.27)**	-0.24 (1.30)	-0.32 (1.31)	-0.28 (1.31)	-0.28 (1.34)	-0.28 (1.34)
	700	-0.09 (**0.97**)	**-0.08** (**0.97**)	-0.20 (0.99)	-0.17 (0.98)	-0.12 (0.98)	-0.09 (0.98)
	500	-0.03 (0.92)	-0.03 (**0.91**)	+0.02 (0.93)	**+0.01** (0.92)	**-0.01** (0.93)	**-0.01** (0.92)
RH (%)	850	**+0.1** (13.5)	+1.2 (13.6)	**-0.1 (13.1)**	-0.2 (13.2)	+0.2 (14.5)	+0.4 (14.5)
	700	-1.1 (16.6)	-0.7 (16.5)	-0.3 (**16.4**)	**-0.2** (16.5)	-1.5 (17.1)	-1.4 (17.2)
	500	**-0.4 (19.9)**	**+0.4** (20.0)	+1.6 (20.6)	+2.3 (20.8)	-1.2 (20.1)	-0.7 (20.2)
Z (m)	850	-4.4 (11.7)	-4.5 (11.7)	**-3.8** (11.6)	**-3.8 (11.2)**	-4.4 (11.8)	-4.6 (11.9)
	700	**-5.3 (12.1)**	-5.5 (12.3)	-5.9 (12.6)	-5.5 (**12.1**)	-5.6 (12.5)	-5.7 (12.5)
	500	**-5.6** (14.3)	-5.7 (14.4)	-6.3 (14.6)	-5.9 (**13.9**)	-5.9 (14.5)	-6.0 (14.5)
WIND (m/s)	850	**4.01**	4.02	4.09	4.09	4.04	4.04
	700	**3.82**	3.84	3.87	3.87	3.86	3.87
	500	4.11	4.11	4.13	4.12	4.11	**4.10**

Table 2. *ME (and RMSE) of temperature, relative humidity, geopotencial height and MVWE of wind for 24-hr forecasts initialized at 00Z, corresponding to grid to grid verification over the 36-km domain. The best results are marked in bold.*

TEMPERATURE: It is underestimated in the lowest levels but overestimated at 300 hPa. Error increases with forecast length but decreases with height (see Table 2), except for the upper levels (500 and 300 hPa). **Best results with the KF** cumulus scheme.

RELATIVE HUMIDITY: The forecasts are more biased in upper levels (see Table 2), where they tend to be moister. The configurations with the BMJ cumulus scheme are the driest in lower levels but the moistest in upper levels. The RMSE score tends to increase with height.

GEOPOTENCIAL HEIGHT tends to be underestimated (see Table 2). The S1 score (not shown) gives the **best results with the KF.WSM5** configuration.

MVWE has similar values in all the configurations (see Table 2).

5.2. Point to point: 12-km domain

TEMPERATURE (not shown)

- The errors are low in general (with RMSE ranging from 0.9 to 2.0ºC) in all vertical profiles.
- It is usually overestimated in upper levels (ME between +0.1 and +1.0ºC), but the behavior in lower levels depends on the site (in Palma is more biased towards negative values than in Barcelona).
- The configurations with the GD and KF cumulus schemes behave more regularly than the others.

WIND (not shown)

- The MVWE in lower and upper levels tends to be higher than in medium levels.
- The configurations with best forecasts are those using the KF and the BMJ cumulus schemes.

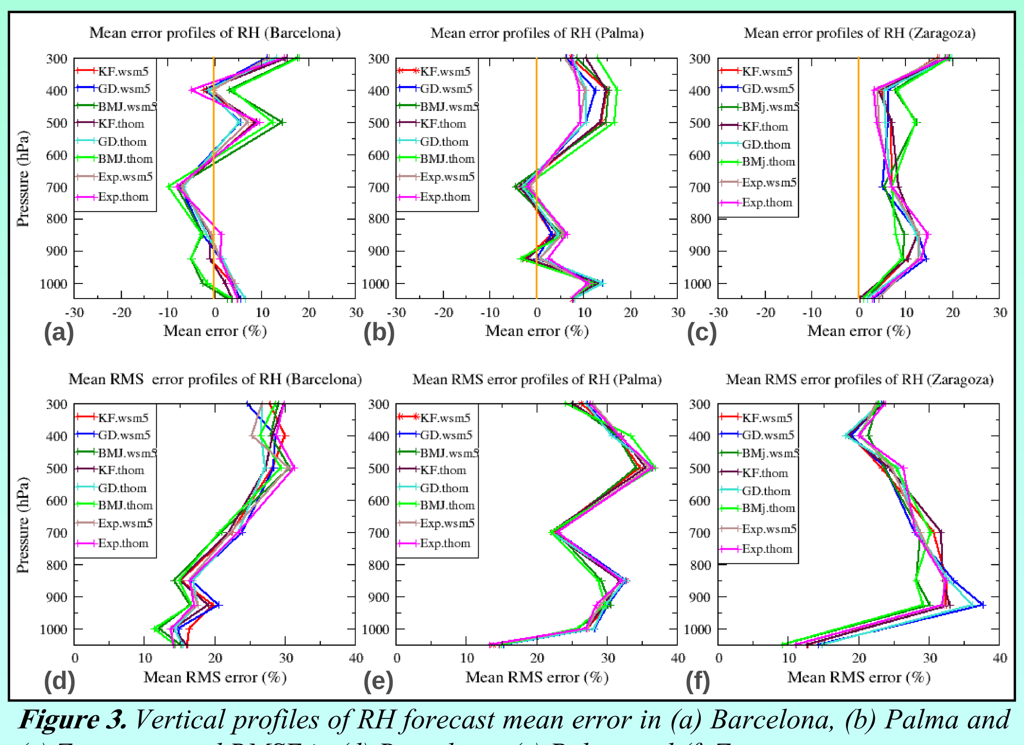


Figure 3. *Vertical profiles of RH forecast mean error in (a) Barcelona, (b) Palma and (c) Zaragoza, and RMSE in (d) Barcelona, (e) Palma and (f) Zaragoza.*

RELATIVE HUMIDITY

- The ME (Figure 3a-c) is low (-10,15%) in the 3 sites and for all levels.
- In Barcelona and Palma, the model is moist at lower levels and very moist in upper levels; in Zaragoza the whole vertical profile is too moist.
- The RMSE (Figure 3d-f) tends to increase with height in lower levels, while from the 500 to 300 hPa decreases in Barcelona and Palma.

Almost all the configurations give similar results, except the combination of EXP.Thom, that provide worse results.

5.3. QPF Verification: 12-km domain

The first objective is to select a subgroup of the best configurations among all the eight in order to study them more carefully.

✗ **BMJ.WSM5**, ✗ **BMJ.Thom**: The configurations with the BMJ scheme are discarded because they show to be **useless for high intensities**. Despite being skillful in less intense episodes, they usually miss the most intense events.

✓ **EXP.WSM5**, ✗ **EXP.Thom**: The configurations that explicitly resolve convection have a **low skill for lower intensity** thresholds but achieve **the best forecasts for some events of high intensity**, for which they may be useful. However, only EXP.WSM5 has been selected because of the worst results of EXP.Thom in conventional variables.

✗ **KF.WSM5**, ✓ **KF.Thom**, ✗ **GD.WSM5**, ✓ **GD.Thom**: These configurations do not have an optimal behavior biased towards low or high intensities.

It is difficult to choose which of the four configurations performs best; however, only those with the Thompson microphysical scheme are selected, because of their slightly better results than the other couple of configurations.

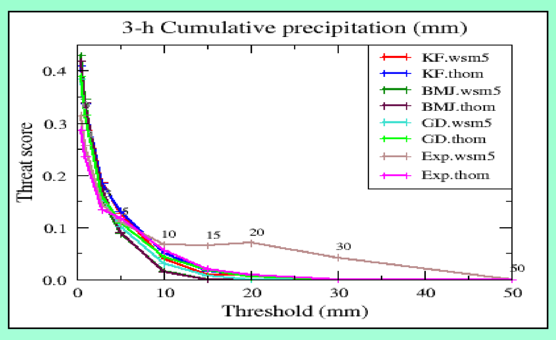


Figure 4. *CSI against intensity threshold for all simulations initialized at 00Z for 3-hour accumulated precipitation between 12-15 Z.*

Now, let's evaluate the most common QPF verification indexes for the three final configurations: **KF.Thom, GD.Thom** and **EXP.WSM5:**

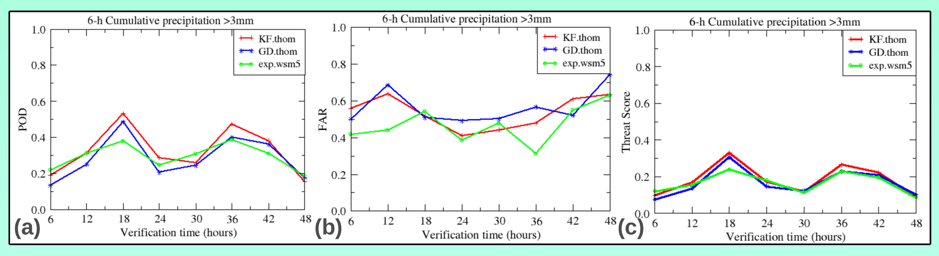


Figure 5. *Temporal evolution of (a) POD, (b) FAR and (c) CSI scores, averaged over all simulations initialized at 00Z for the three chosen configurations, corresponding to the 6-h accumulated QPF > 3 mm.*

1) Maximum POD and CSI values at 18 and 36 hours length of forecast.
   ⇨ When most convective activity is observed in the area *(12-18Z of the 1st day and 06-12Z of the 2nd).*
2) The KF.Thom configuration has a better skill than the GD.Thom at almost all forecast hours, because while the POD index is higher, the FAR is lower.
   ⇨ The CSI is consequently higher with KF.Thom
3) In periods when the POD and CSI scores increase, the FAR index decreases.
   ⇨ This fact demonstrates a good performance of the rain forecasts.

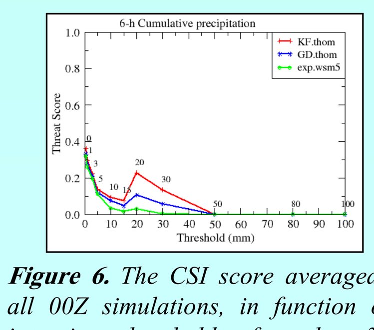


Figure 6. *The CSI score averaged over all 00Z simulations, in function of the intensity threshold, for the 36-42h forecast length interval.*

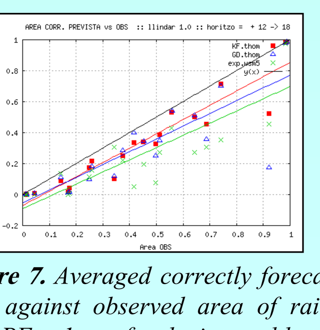


Figure 7. *Averaged correctly forecasted area against observed area of rainfall for QPF > 1 mm for the interval between +12 and 18 hr.*

4) Interestingly, the EXP.WSM5 configuration gives the highest CSI and POD indexes during the night, but has the poorest skill in daytime hours.
5) In Figures 6 and 7, the performance of the model is shown in different ways for two afternoon 6-hour intervals (corresponding to the 1st day in Figure 7 and to the 2nd day in Figure 6):
   - For lower precipitation thresholds (< 5 mm) all the configurations have a similar skill. However, KF.Thom performs the best for higher amounts of rain.
   - The averaged correctly forecasted area against observed area for QPF > 1 mm displayed in Figure 7 shows the best matching between forecasts and observations given by KF.Thom.

The analyses of all these results indicate the KF.Thom configuration is the most skillful and it has the most consistent behavior.

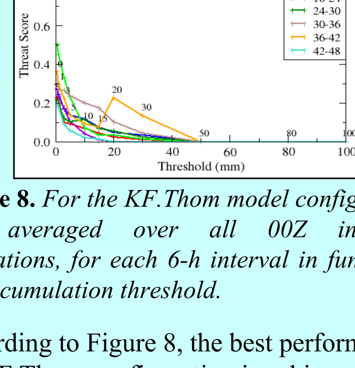


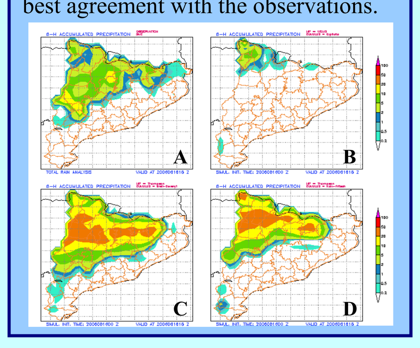
Figure 8. *For the KF.Thom model configuration, CSI averaged over all 00Z initialized simulations, for each 6-h interval in function of the accumulation threshold.*

According to Figure 8, the best performance of the KF.Thom configuration is achieved at:
- 12-18 UTC of the 1st day with light rain.
- 06-12 UTC of the 2nd day with moderate QPF.
- 12-18 UTC of the 2nd day with heavy rainfall.

EYEBALL VERIFICATION BOX

Example for the 16th June, 2006 case

The observed rainfall field (A) between 12-18 UTC is compared with the 6-h accumulation forecasts given by EXP.WSM5 (B), GD.Thom (C) and KF.Thom (D). The 2 latter show the best agreement with the observations.



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6. CONCLUSIONS

In this work, the sensitivity of the WRF-ARW v2.2 model has been evaluated using combinations of the different cumulus parameterizations with the WSM5 and Thompson microphysical schemes, in order to find the best configuration for operational forecasts in SMC.

For both domains, the verification of the conventional variables (T, Z, RH) has been done by the computation of the ME and RMSE indexes and the MVWE for wind. Furthermore, QPF has been verified in the inner domain using classical statistic scores (POD, FAR, CSI) derived from a contingency table.

The best results for the coarser domain have been achieved by the KF.WSM5 configuration, while for the inner domain, according to the results from the QPF verification, the KF.Thom configuration showed the best skill.

These two configurations will be used for operational forecasts in SMC, and these will be verified against the other models that are currently operationally run in SMC (MM5 model, MASS model and Lokal Modell).