

Figure 1. Study area and stations location over the study area. a) Nested domains for the WRF model experiments showing the outermost domain (D01) with 25-km of resolution, the middle domain (D02) with 5 km of resolution and the innermost domain (D03) with 1-km of resolution. The D03 frame mark the study area; b) Longitudinal maximum elevation profile for the 1-km domain; c) Location of the rain-gauge stations (yellow dots) over the 1-km domain and the location of Pousadas (red triangle).

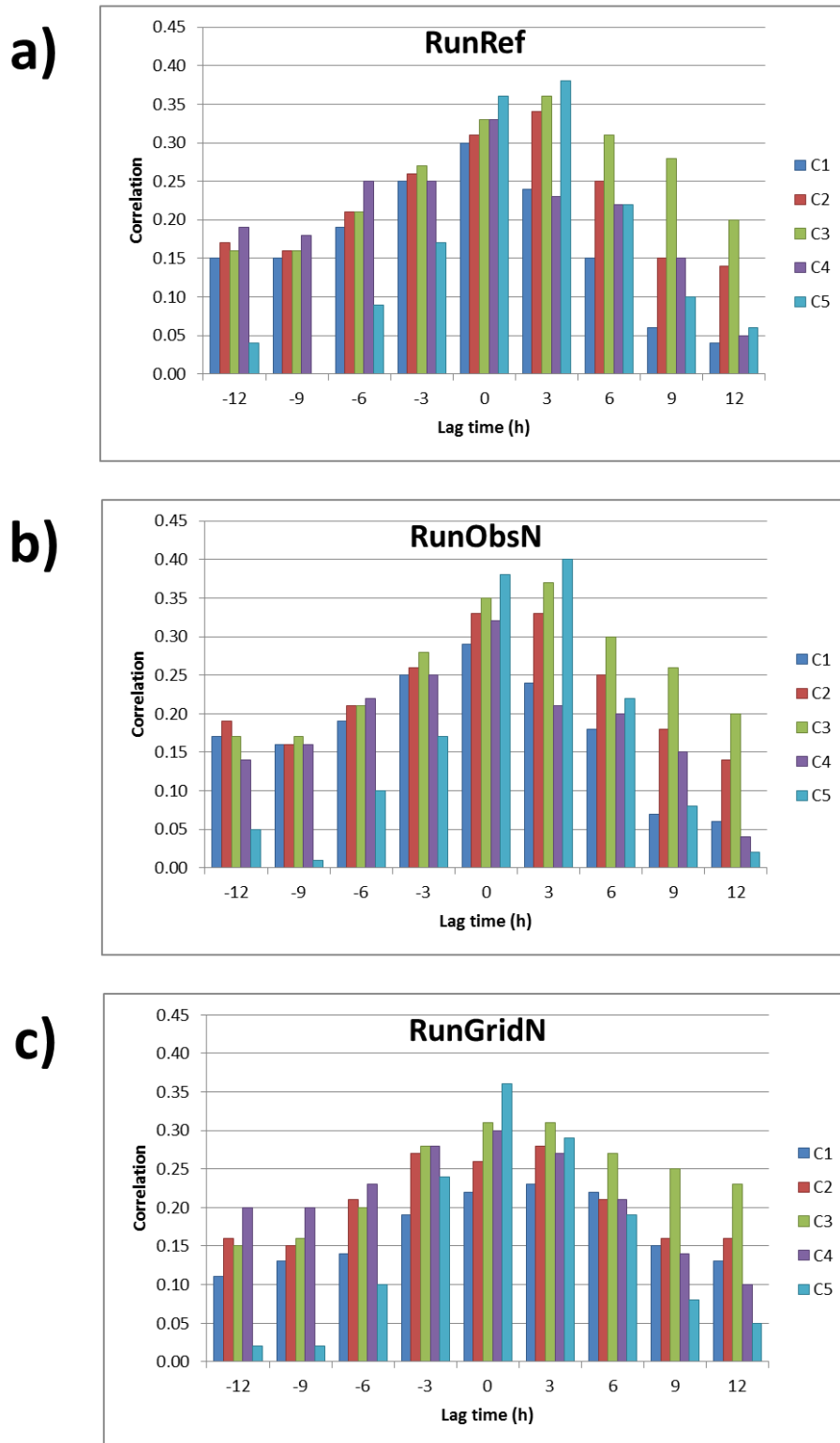


Figure 2 Lag correlation between observations and the model series for the three experiments grouped by classes of altitude (C1 to C5).

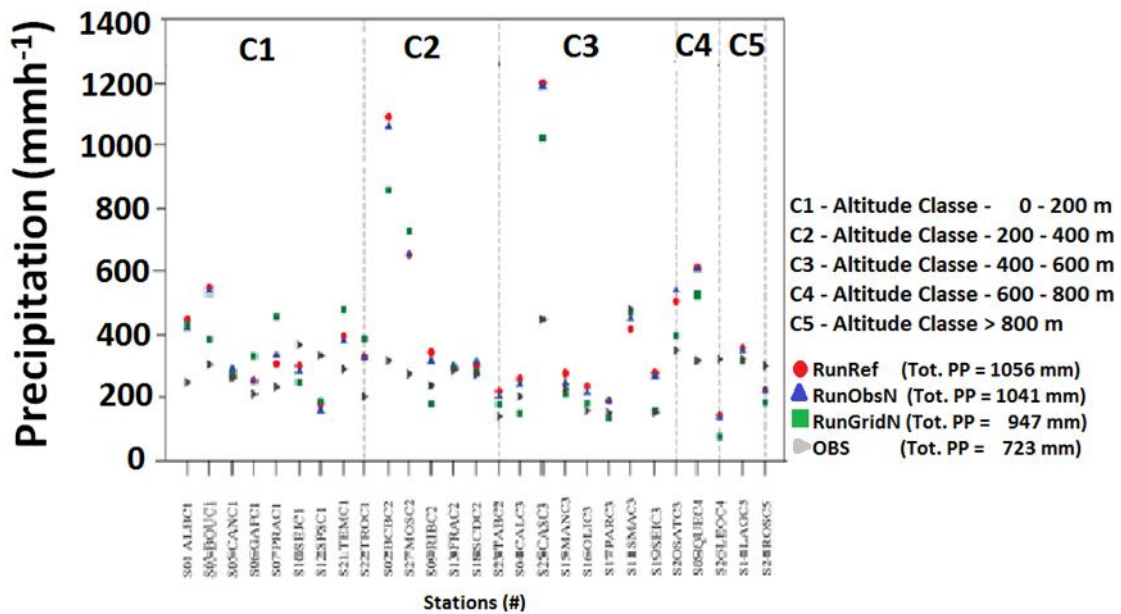


Figure 3. Monthly accumulated precipitation for the simulation period (mm) over the study domain grouped by altitude classes. The observed amounts are depicted as a grey triangle and for each of the model simulations as: RunRef (red circle), RunObsN (blue triangle) and the RunGridN (green square). The Caption box also shows the total rainfall observed and simulated by the model in each case.

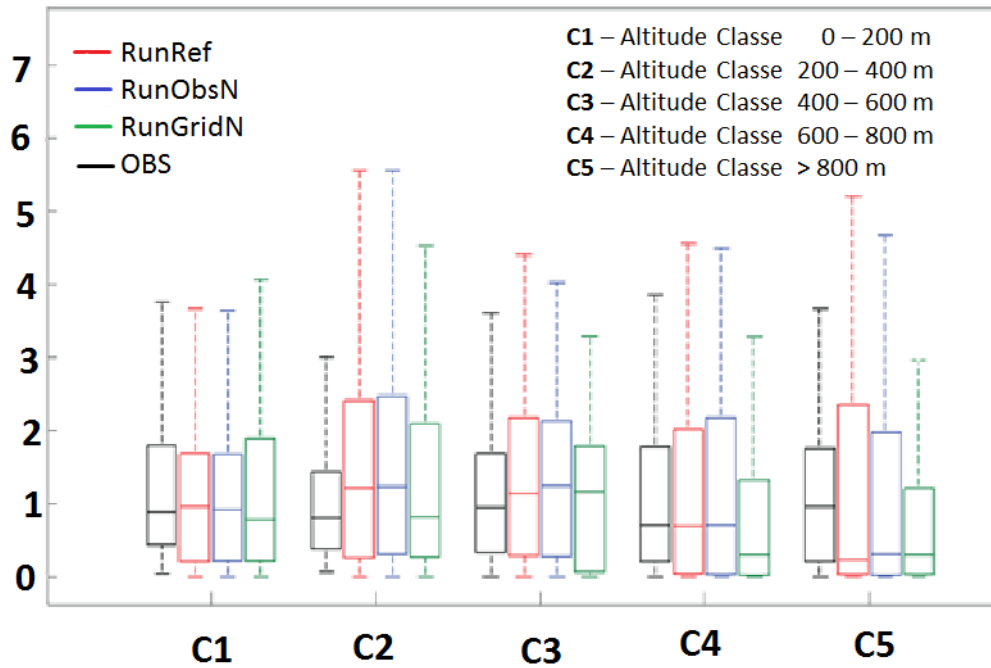


Figure 4. Box plot for the observations and for the three experiments. The horizontal box line represents the median (50th percentile), the lower line the 25th percentile, the upper line the 75th percentile. The dashed lines represents 1.5 times IQR.

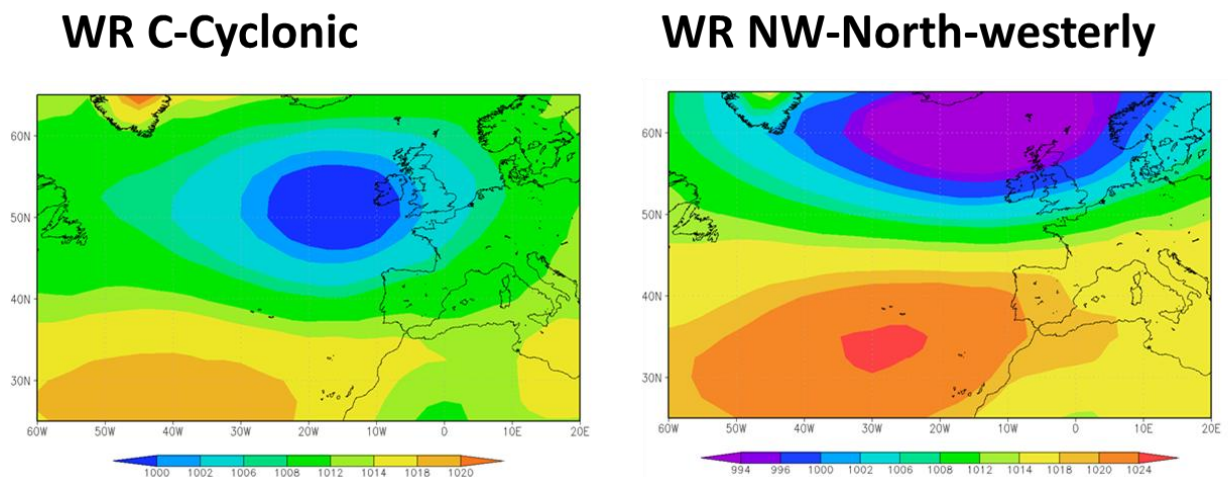


Figure 5. Weather regimes (WR) for the regime cyclonic (left) and north-westerly (right). average for the time period between 1948-2011. Adapted from Santos et al. (2005).

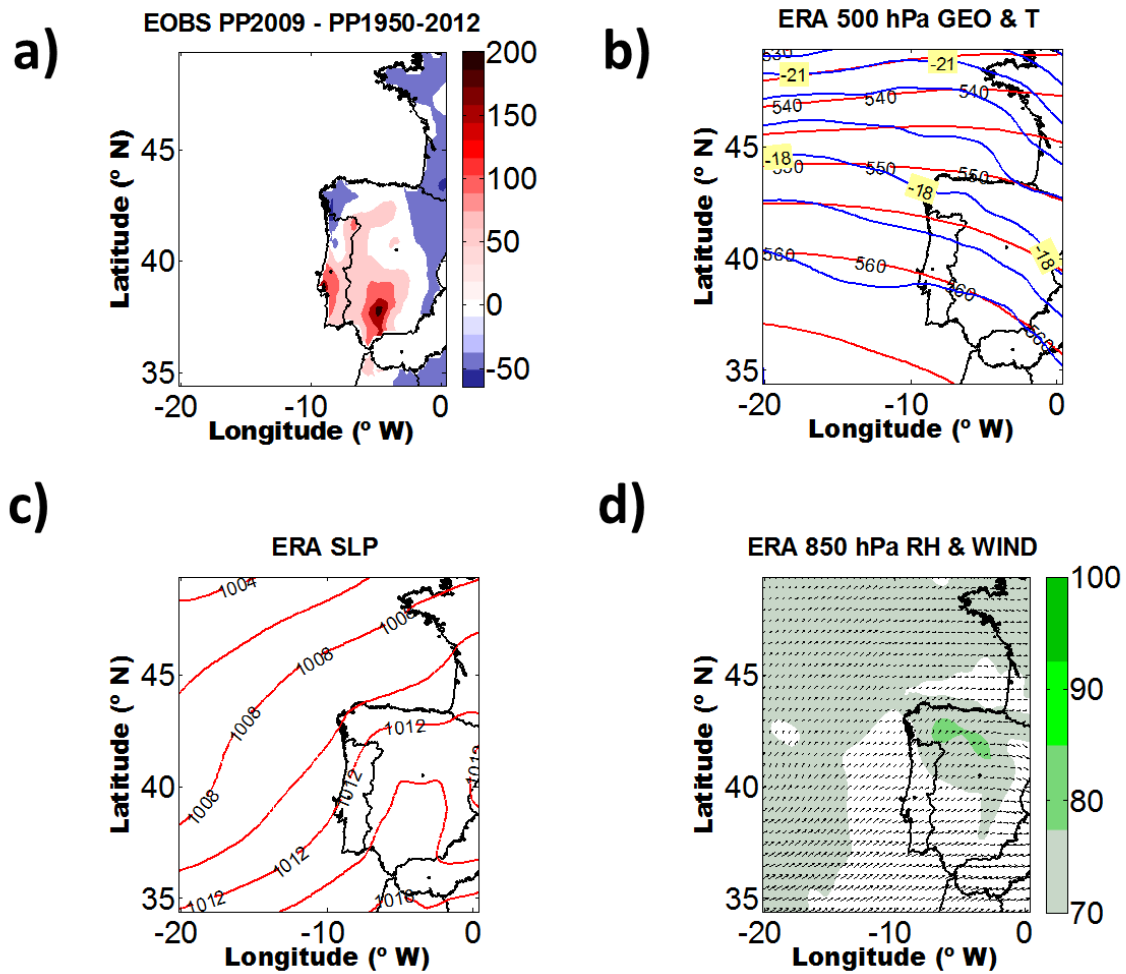


Figure 6. a) Precipitation difference between December 2009 and the December climatology period (1950-2012). December 2009 monthly averaged b) 500 hPa geopotential height (dam, red contour) and temperature (K, blue contour); c) sea level pressure (hPa) and d) 850 hPa relative humidity (%), colour shaded) and wind vector (ms⁻¹). The observations are from the ERA dataset except for precipitation that are from EOBS dataset.

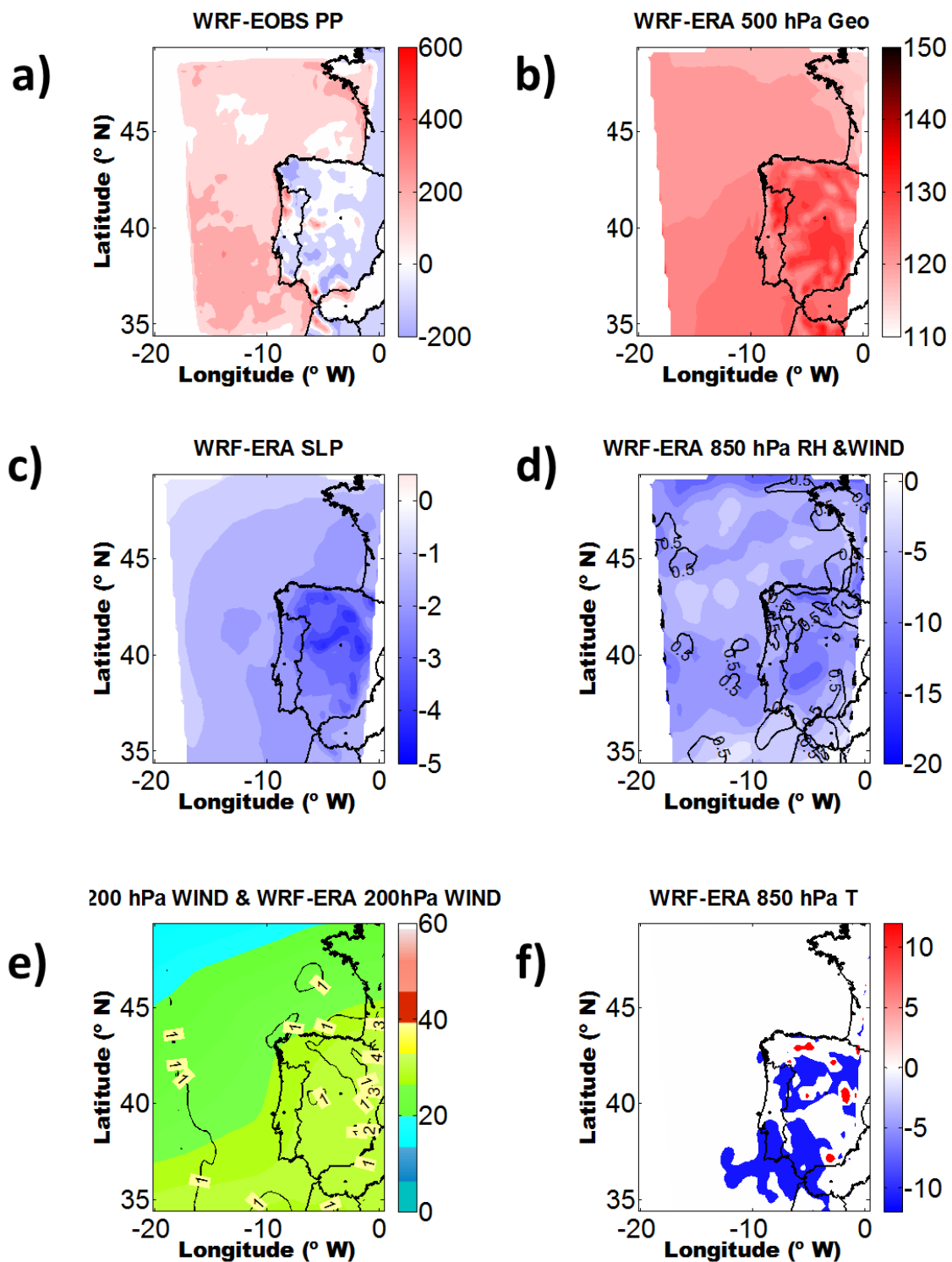
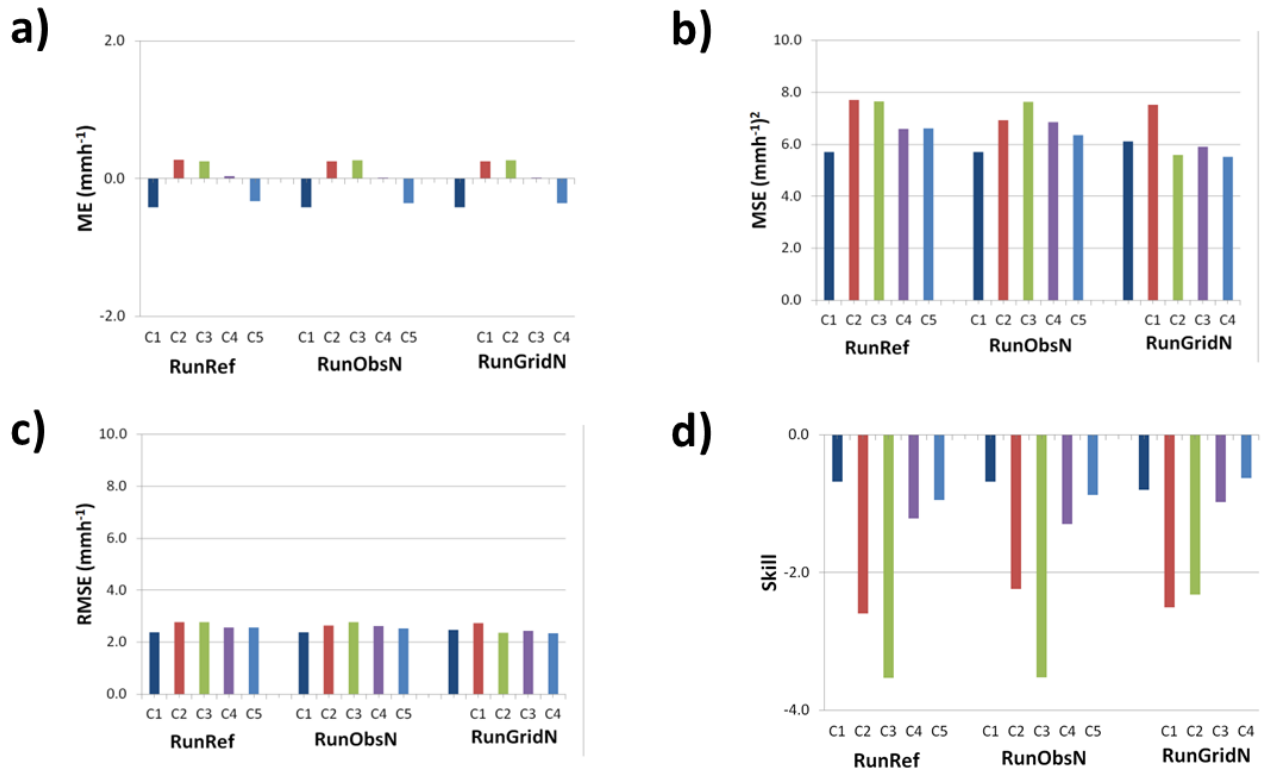
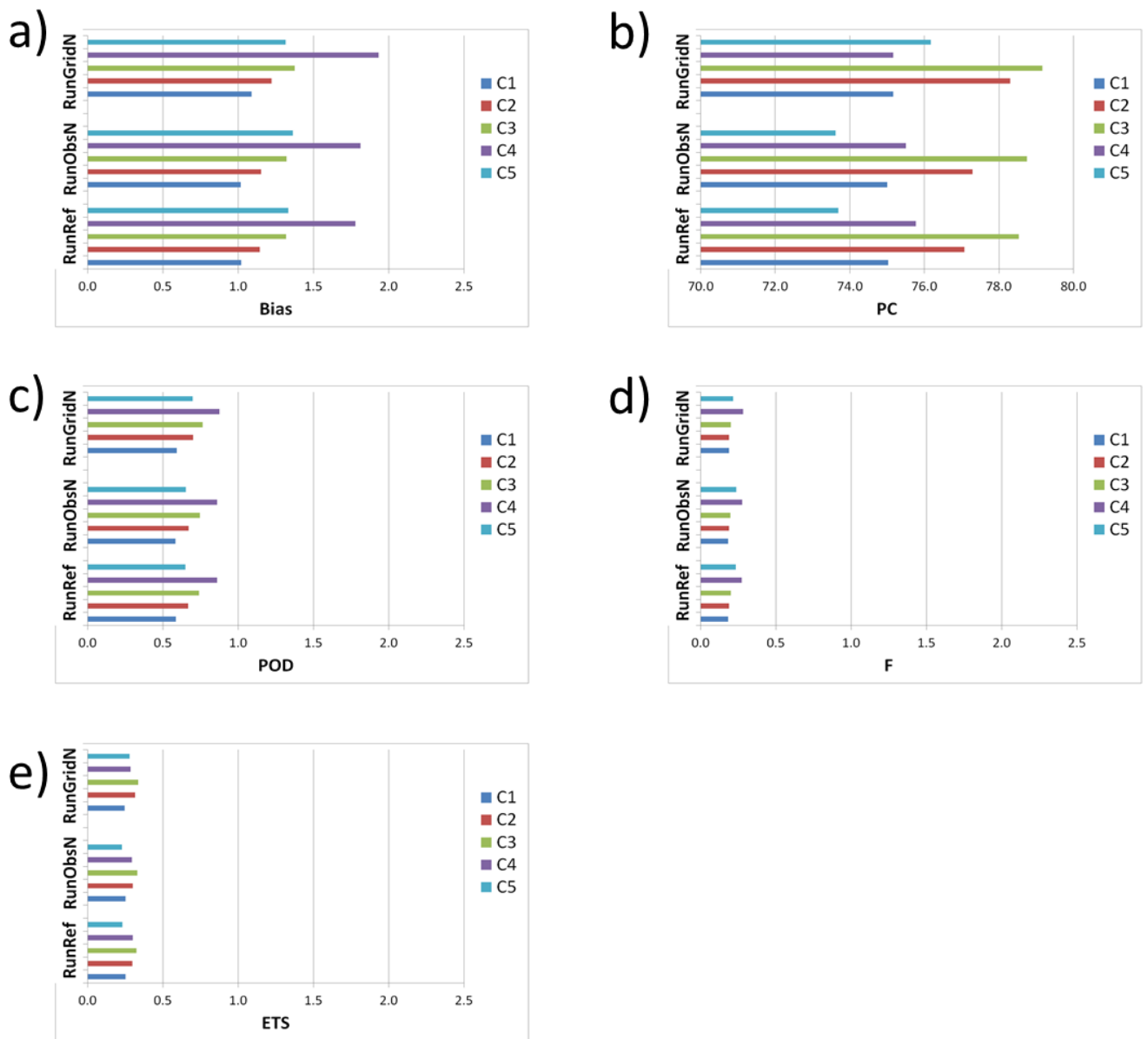


Figure 7. Averaged differences between the WRF and ERA/observations , during December 2009, for a) precipitation (mm), b) 500 hPa geopotential height (dam), c) sea level pressure (hPa), d) 850hPa relative humidity (% , colour shaded) and wind differences (ms-1,contour) e) 200 hPa observed wind speed (ms-1) averaged for December 2009 (shaded) and the difference between WRF and observations (contour) and f) 850 hPa temperature(K). The observations are from the ERA dataset except for precipitation that are from EOBS dataset.



*ME –mean error ; *MSE-mean square error; *RMSE –root mean square error; *Skill

Figure 8. Continuous verification measurements of the hourly precipitation (above 0.1 mm/h) for the stations grouped by altitude class. The red bars denote negative values of the measurements and the positive are presented by the blue bars.



*B – frequency bias; *PC- percentage of correct events; *POD – probability of detection; *F – false alarm rate; *ETS – equitable threat score

Figure 10. Categorical verification measurements for hourly precipitation (above 0.1 mm/h) for stations grouped by altitude

Table 1 Basic precipitation statistics for each station for December 2009.

Station	Station ID	Monthly rainfall December 2009		Long-term observed data				Maximum daily rainfall December 2009		Long-term observed data			
		Total (mm)	Median	Dec 2009 vs. Median	Percentile (of all obs. data)	Return period (yrs)	Number of Years	Total (mm)	Median	Dec 2009 vs. Median	Percentile	Return period (yrs)	Number of Years
Bouçã	S03BOUC1	296.8	258.3	15%	67%	2.9	25	47	51.5	-9%	41%	1.7	23
São Pedro do Sul	S12SPSC1	130.7	119.1	10%	54%	2.2	55	53.6	32.5	65%	89%	7.7	45
Tentúgal	S21TEMC1	285.0	126.7	125%	89%	8.1	56	69.1	33.4	107%	96%	18.3	54
Trouxemil	S22TROC1	196.5	127.6	54%	71%	3.3	29	45.7	27.0	69%	93%	10.0	29
Barragem de Castelo Burgães	S02BCBC2	301.9	214.5	41%	69%	3.1	71	48.6	48.6	0%	50%	2.0	37
Mosteiro de Cabril	S27MOSC2	204.3	159.5	28%	63%	2.7	60	56.2	33.0	70%	90%	7.3	21
Fragosela	S13FRAC2	277.4	79.45	249%	95%	11.5	22	49.5	24.0	106%	90%	7.3	21
Santa Comba Dão	S18SCDC2	262.6	110.7	137%	83%	5.6	77	66.4	32.1	107%	95%	15.6	77
Calde	S04CALC3	196.1	115.2	70%	70%	3.1	24	22.7	29.9	-24%	30%	1.5	24
Oliveira do Hospital	S16OLIC3	144.9	107.1	35%	59%	2.4	78	19.5	27.4	-29%	29%	1.4	79
Sátão	S20SATC3	340.1	111.7	204%	91%	9.8	48	51.9	33.3	56%	89%	8.2	48
Lagoa Comprida	S14LAGC5	366.7	201.5	82%	79%	4.5	47	142.8	63.0	127%	>95%	>6	12

Table 2. Maximum rainfall (mm) according to return period and maximum observed in December 2009 for the S18SCDC2 station (Brandão et al., 2001).

Return period (yrs)	Duration (hrs)						
	1	2	3	6	12	24	48
2	17.5	22.4	25.9	33.3	43.1	55.4	71.2
5	25.1	31.7	36.3	45.8	57.9	73.2	92.4
10	30.0	37.7	43.1	54.1	67.2	85.3	108.3
50	41.1	51.1	58.1	72.3	88.4	111.6	141.0
100	45.7	56.8	64.4	80.0	97.3	122.7	154.7
Maximum for December 2009	9.6	14.5	18.7	34.5	49.1	67.6	68.2

Table 3. Contingency table of counts for a binary type of event.

		Yes Obs Rain $\geq t$	no Obs Rain $< t$
yes	WRF Rain $\geq t$	a (hits)	b (false alarms)
no	WRF Rain $< t$	c (misses)	d (correct negatives)

Table 4. Mean absolute error (MD) between the simulations and the observations for each location grouped by altitude class.

Altitude Classes	WRF Experiments	Stations								
		S01ALBC1	S03BOUC1	S05CANC1	S06GAFC1	S07PRAC1	S10SEJC1	S12SPSC1	S21TEMC1	S22TROC1
C1	RunRef	0.65	0.72	0.45	0.45	0.48	0.55	0.42	0.64	0.51
	RunObsN	0.63	0.71	0.47	0.44	0.53	0.53	0.41	0.61	0.5
	RunGridN	0.65	0.61	0.51	0.56	0.77	0.54	0.47	0.74	0.58
		<hr/>								
		S02BCBC2	S27MOSC2	S09RIBC2	S13FRAC2	S18SCDC2	S23TABC2			
C2	RunRef	1.33	0.92	0.5	0.42	0.49	0.35			
	RunObsN	1.28	0.91	0.46	0.44	0.48	0.33			
	RunGridN	1.09	0.95	0.38	0.48	0.5	0.31			
		<hr/>								
		S04CALC3	S25CASC3	S15MANC3	S16OLIC3	S17PARC3	S11SMAC3	S19SEIC3	S20SATC3	
C3	RunRef	0.41	1.5	0.39	0.36	0.31	0.72	0.39	0.66	
	RunObsN	0.39	1.5	0.35	0.33	0.3	0.74	0.37	0.68	
	RunGridN	0.33	1.25	0.33	0.29	0.26	0.72	0.28	0.53	
		<hr/>								
		S08QUEC4	S26LEOC4							
C4	RunRef	0.78	0.42							
	RunObsN	0.79	0.41							
	RunGridN	0.72	0.4							
		<hr/>								
		S14LAGC5	S24ROSC5							
C5	RunRef	0.58	0.45							
	RunObsN	0.57	0.44							
	RunGridN	0.54	0.41							

Table 5. Daily weather regime classification for December 2009.

Number of Days (d)	Weather Types	EOBS PP (mm)	WRF PP (mm)
6	NW	16	38
3	AA	1	1
12	C	109	151
8	E	16	22
2	R	9	13

Table 6. Statistical measurements. Mean Error (ME), Root Mean Square Error (RMSE) and Pattern Correlation Coefficient (PC) for the WRF simulations relative to Observations.

	ME	RMSE	PC
PP (mm/3h)	0.16	7.39	0.26
500 hPa GEO (dam)	229.33	90.40	0.48
SLP(hPa)	3.42	7.44	0.14
850 hPa RH (%)	-0.79	25.81	0.04
850 hPa U (ms ⁻¹)	1.89	7.84	0.02
850 hPa V (ms ⁻¹)	0.05	7.18	-0.03
200 hPa U (ms ⁻¹)	-7.97	15.91	-0.19
200hPa V (ms ⁻¹)	-2.27	13.21	-0.08
850 hPa T (K)	2.27	2.74	0.57

*PP –precipitation ; *GEO – geopotential height; *SLP –sea level pressure; *RH – Relative humiditu; U – zonal component of wind; V – meridional component of wind

Table 7. Verification measures of hourly precipitation for the December 2009 evaluation period (745 hours of simulation) for the three WRF model experiments: RunRef, RunObsN and RunGridN.

Threshold (mm/h)	WRF Experiments	B	PC (%)	POD	F	ETS	ME (mm/h)	MSE (mm/h)²	RMSE (mm/h)	SS
<i>t=0.1</i>	RunRef	1.2	77	0.7	0.2	0.3	0	6.9	2.6	-1.7
	RunObsN	1.2	77	0.7	0.2	0.3	0	6.7	2.6	-1.6
	RunGridN	1.3	77	0.7	0.2	0.3	-0.2	6.2	2.5	-1.4
<i>t=1</i>	RunRef	0.8	85	0.4	0.1	0.2	-0.8	10.6	3.3	-0.7
	RunObsN	0.8	85	0.4	0.1	0.2	-0.8	10.5	3.2	-0.7
	RunGridN	0.9	84	0.4	0.1	0.2	-1.1	9.7	3.1	-0.5
<i>t=2</i>	RunRef	0.7	90	0.2	0	0.1	-1.7	14.8	3.8	-0.2
	RunObsN	0.7	90	0.2	0	0.1	-1.7	14.5	3.8	-0.2
	RunGridN	0.8	90	0.2	0	0.1	-2.1	14	3.7	-0.2
<i>t=3</i>	RunRef	0.6	93	0.2	0	0.1	-2.6	21	4.6	0
	RunObsN	0.6	93	0.2	0	0.1	-2.6	20.8	4.6	0
	RunGridN	0.7	93	0.1	0	0.1	-3	20.8	4.6	0