

Climate change projections of dry and wet events in Iberia based on the WASP-Index

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Supplementary material

Following the selected methodology (Figure 3), the duration (Figures 7 and 8), intensity (Figures 10 and 11), and frequency of occurrence (Figures 12 and 13) for intermediate-to-severe wet and dry events for 12m-WASP were computed for the past periods 1961–1990 and 1981–2010, and the future periods 2021–2050 and 2041–2070, under RCP4.5 and RCP8.5. The 12m-WASP anomalies (Δ) between 2041–2070, for both RCPs, and 1961–1990 are presented for the duration (Figure 9) and frequency of occurrence (Figure 14) of wet and dry events. The corresponding tables for intensity (Table S1), duration (Table S2), and frequency (Table S3) are analyzed for several IP main cities (within NUTS 2 regions) and are presented as Supplementary Material.

The spatial variability for the duration is also expressed in Table S1 that shows the temporal evolution in the main IP cities. The anomalies Δ computed between the period 2041–2070 and the baseline climate 1961–1990, under both RCPs, reveal that for Valencia (–20.2 and –22.5), Murcia (–20.3 and –20.9), Seville (–22.1 and –25.9), Logroño (–23.9 and –20.3), and Santiago de Compostela (–20.2 and –2.8) there is a predicted decrease in the number of intermediate-to-severe wet events, whereas the opposite is verified for Barcelona (15.0 and 11.9) and Merida (12.2 and 12.8), in Spain, and Faro (20.5 and 5.3), Lisbon (24.7 and 15.1), Guarda (13.5 and 12.1), Porto (9.5 and 17.2), Aveiro (7.8 and 15.4), in Portugal. The majority of the main Portuguese cities reveal positive anomalies, except for Bragança (–1.6 and –2.2), in the Norte region, Coimbra (–2.3 and 3.6), in the Centro region, and Beja (3.5 and –9.5) in the inner south.

The projections reveal positive anomalies (Figures 9c and d) for all the main IP cities for the intermediate-to-severe dry events, with higher values when compared with the wet events under both RCPs. The most striking changes are found for Bilbao (56.9 and 74.6), Pamplona (42.9 and 34.7), Vitoria (42.7 and 37.7), Seville (40.3 and 44.3), Madrid (35.4 and 39.3), Murcia (40.8 and 27), and Barcelona (40.2 and 16.5) in Spain; but also, Faro (33.7 and 65), Porto (42.1 and 29.4), Lisbon (34.6 and 40.9), Beja (28 and 43.1), Santarém (33.5 and 39.3), Évora (25.4 and 38), Aveiro (33.5 and 21.7) and Bragança (25.5 and 32.1) in Portugal under both RCP4.5 and RCP8.5 (Table S1). These changes in the anomalies project increases in the duration of dry conditions between 30 to 74.6 months, e.g., 2.5 to approximately 6 years. Lastly, there is no coherent change between the RCPs. The projections depend on the location, hinting at a spatial variability of the projected climate change impacts in Iberia.

For the intermediate-to-severe dry events (Table S2), most cities have negative anomalies and, since the WASP scale for the dry events is also negative, the more negative the more severe is projected to be the future dry conditions. As previously, small values for the anomalies were found throughout Iberia, again except for Oviedo (–1.17 and –1.25), Bilbao (–1.97 and –2.01) and Barcelona (–1.96 and –1.94), in Spain, and Porto (–2.07 and –1.9), Aveiro (–1.85 and –1.64), Lisbon (–2.01 and –2) and Faro (–2.06 and –1.71), in Portugal, which may undergo the most extreme conditions in 2041–2070 under RCP4.5 and RCP8.5, respectively. The results show only two exceptions with small positive anomalies, namely for Zaragoza (–0.17 and 0.09) and Guarda (–0.14 and 0.02). Overall, the analysis of the intensity, either for intermediate-to-severe wet and dry events, highlights an increase of extreme events (wet or dry), mainly for the severe dry

Table S1. Duration (in months) for wet (dry) intermediate-to-severe events for the 12m-WASP for the historical periods 1961–1990 and 1981–2010 and, 2021–2050 and 2041–2070 under RCP4.5 and RCP8.5 for the main IP cities (note that $\Delta(41-70 - 61-90)$).

Wet events			RCP4.5			RCP8.5		
City	1961–1990	1981–2010	2021–2050	2041–2070	Δ	2021–2050	2041–2070	Δ
Oviedo	7.6	1.3	4.9	5.4	-2.2	19.8	19.2	11.6↑
Santiago de Compostela	21.8	10.0	10.4	1.6	-20.2↓	7.6	19.1	-2.8
Zaragoza	24.5	21.5	11.5	20.5	-4.0	10.0	10.2	-14.2↓
Valencia	24.8	19.1	17.6	2.0	-22.8↓	15.6	2.3	-22.5↓
Merida	11.9	15.8	16.1	24.1	12.2↑	9.9	24.7	12.8↑
Seville	31.8	22.0	4.4	9.7	-22.1↓	10.9	6.0	-25.9↓
Pamplona	6.8	3.4	9.7	9.5	2.8	2.5	2.0	-4.8
Logroño	27.1	8.3	2.7	3.2	-23.9↓	10.9	6.7	-20.3↓
Valladolid	9.7	16.8	9.4	14.7	5.1	1.5	13.4	3.8
Madrid	23.9	3.2	9.9	14.3	-9.6	3.3	5.5	-18.3↓
Toledo	10.5	12.2	9.1	23.8	13.3↑	7.6	18.4	7.9
Bilbao	0.0	0.0	1.5	6.0	6.0	12.1	16.7	16.7↑
Vitoria	15.4	0.4	1.0	4.7	-10.7↓	6.5	6.4	-8.9
Murcia	23.4	17.2	7.0	2.9	-20.4↓	2.2	2.5	-20.9↓
Barcelona	0.0	0.0	9.9	15.0	15.0↑	8.2	11.9	11.9↑
<i>Porto</i>	0.0	0.0	9.5	9.5	9.5	4.0	17.2	17.2↑
<i>Aveiro</i>	2.8	1.2	10.5	10.5	7.8	1.5	18.2	15.4↑
<i>Bragança</i>	14.7	16.3	16.1	13.1	-1.6	4.6	12.5	-2.2
<i>Guarda</i>	10.5	0.0	16.7	24.1	13.5↑	5.3	22.6	12.1↑
<i>Coimbra</i>	17.3	7.3	15.1	15.1	-2.3	3.8	20.6	3.2
<i>Castelo Branco</i>	13.1	6.7	19.7	22.3	9.2	4.3	18.2	5.1
<i>Santarem</i>	15.8	31.5	20.9	21.0	5.1	4.3	19.5	3.7
<i>Lisbon</i>	0.0	0.0	22.3	24.7	24.7↑	6.9	15.1	15.1↑
<i>Évora</i>	18.1	13.8	15.1	21.8	3.8	2.9	19.7	1.6
<i>Beja</i>	23.5	30.1	18.0	27.0	3.5	4.8	14.0	-9.5
<i>Faro</i>	2.3	1.8	19.2	22.8	20.5↑	4.9	7.6	5.3
Dry events			RCP4.5			RCP8.5		
City	1961–1990	1981–2010	2021–2050	2041–2070	Δ	2021–2050	2041–2070	Δ
Oviedo	5.0	8.5	57.9	27.3	22.3↑	9.0	31.4	26.4↑
Santiago de Compostela	17.0	27.6	28.9	24.0	6.9	16.6	19.3	2.3
Zaragoza	4.8	14.7	24.9	29.3	24.5↑	40.4	13.0	8.2
Valencia	7.7	2.0	16.0	34.8	27.1↑	10.1	12.6	4.9
Merida	4.1	28.0	23.6	21.2	17.1↑	51.8	31.3	27.2↑
Seville	2.8	24.2	40.3	43.1	40.3↑	49.9	47.1	44.3↑
Pamplona	7.1	12.8	35.6	50.0	42.9↑	38.5	41.8	34.7↑
Logroño	9.7	16.3	40.7	37.1	27.4↑	22.6	33.0	23.3↑
Valladolid	8.9	21.0	51.4	25.9	16.9↑	43.8	30.9	21.9↑
Madrid	13.8	36.9	40.1	49.2	35.4↑	56.7	53.0	39.3↑
Toledo	9.2	34.4	34.9	52.8	43.6↑	54.1	44.5	35.3↑
Bilbao	0.0	0.0	58.4	56.9	56.9↑	21.1	74.6	74.6↑
Vitoria	17.5	38.2	61.5	60.2	42.7↑	21.4	55.2	37.7↑
Murcia	6.7	8.6	23.7	47.5	40.8↑	26.0	33.7	27.0↑

Barcelona	0.0	0.0	34.5	40.2	40.2↑	27.5	16.5	16.5↑
<i>Porto</i>	0.0	0.0	51.7	42.1	42.1↑	29.4	29.4	29.4↑
<i>Aveiro</i>	1.0	5.9	41.7	34.5	33.5↑	34.1	22.7	21.7↑
<i>Bragança</i>	5.7	3.7	30.6	31.2	25.5↑	22.7	37.8	32.1↑
<i>Guarda</i>	15.7	62.1	25.5	28.1	12.4↑	29.1	24.6	8.9
<i>Coimbra</i>	6.9	35.5	41.3	28.7	21.8↑	41.0	24.8	17.9↑
<i>Castelo Branco</i>	15.6	37.8	37.9	24.1	8.4	48.4	39.5	23.8↑
<i>Santarem</i>	4.0	15.0	31.4	37.5	33.5↑	52.5	43.3	39.3↑
<i>Lisbon</i>	0.0	0.0	42.7	34.6	34.6↑	53.2	40.9	40.9↑
<i>Évora</i>	5.5	33.2	37.0	30.9	25.4↑	56.2	43.5	38.0↑
<i>Beja</i>	11.1	26.8	38.2	39.0	28.0↑	54.1	54.2	43.1↑
<i>Faro</i>	1.7	3.6	44.3	35.4	33.7↑	64.3	66.7	65.0↑

Table S2. Intensity for wet (dry) intermediate-to-severe events for the 12m-WASP for historical periods 1961–1990 and 1981–2010, and 2021–2050 and 2041–2070 under RCP4.5 and RCP8.5 for the main IP cities (note that $\Delta(41-70 - 61-90)$).

Wet events			RCP4.5			RCP8.5		
City	1961–1990	1981–2010	2021–2050	2041–2070	Δ	2021–2050	2041–2070	Δ
Oviedo	0.81	0.73	1.67	1.68	0.87	2.33	2.35	1.54↑
Santiago de Compostela	2.09	2.74	2.14	1.70	-0.39	2.28	2.17	0.13
Zaragoza	2.07	2.12	2.05	2.03	-0.04	1.91	1.81	-0.38
Valencia	2.38	2.31	1.92	1.74	-0.63	2.34	1.65	-0.74
Merida	1.87	1.90	2.10	2.20	0.33	1.92	1.90	0.10
Seville	1.89	1.78	1.98	2.17	0.28	2.32	1.69	-0.21
Pamplona	1.90	2.01	1.97	1.98	0.09	1.67	1.65	-0.27
Logroño	1.91	2.06	1.78	1.77	-0.14	1.77	1.74	-0.27
Valladolid	1.83	2.13	1.97	1.97	0.14	1.82	1.96	0.04
Madrid	1.79	1.62	1.98	1.92	0.14	1.86	1.61	-0.31
Toledo	1.97	1.69	2.13	1.96	-0.01	1.70	1.91	0.07
Bilbao	0.00	0.00	1.78	1.90	1.90↑	1.93	1.92	1.92↑
Vitoria	1.84	0.48	1.75	1.82	-0.02	1.99	2.02	0.11
Murcia	2.05	1.83	1.76	1.70	-0.35	1.79	1.62	-0.48
Barcelona	0.00	0.00	1.82	1.92	1.92↑	1.83	1.97	1.97↑
<i>Porto</i>	0.00	0.00	2.05	2.05	2.05↑	1.75	1.89	1.89↑
<i>Aveiro</i>	0.32	0.29	2.26	2.26	1.94↑	1.87	2.01	1.69↑
<i>Bragança</i>	2.27	2.37	1.95	2.02	-0.25	1.63	1.83	-0.34
<i>Guarda</i>	2.17	0.00	2.39	2.25	0.08	1.76	1.93	-0.31
<i>Coimbra</i>	2.03	1.80	2.17	2.17	0.14	1.58	2.01	-0.05
<i>Castelo Branco</i>	2.06	1.63	2.18	2.12	0.06	2.11	1.90	-0.11
<i>Santarem</i>	1.98	1.90	2.25	2.25	0.27	2.01	2.00	0.18
<i>Lisbon</i>	0.00	0.00	2.26	2.20	2.20↑	1.98	2.03	2.03↑
<i>Évora</i>	1.85	1.76	2.11	2.00	0.15	1.93	2.03	0.20
<i>Beja</i>	1.89	1.92	2.27	2.07	0.18	1.90	2.01	0.15
<i>Faro</i>	0.19	0.20	1.97	1.94	1.74↑	1.93	1.80	1.60↑
Dry events			RCP4.5			RCP8.5		
City	1961–1990	1981–2010	2021–2050	2041–2070	Δ	2021–2050	2041–2070	Δ
Oviedo	-0.69	-0.71	-1.95	-1.86	-1.17↑	-2.06	-1.95	-1.25↑
Santiago de Compostela	-1.78	-1.77	-1.83	-2.09	-0.30	-2.12	-1.83	-0.04
Zaragoza	-1.87	-1.92	-1.92	-2.04	-0.17	-1.90	-1.78	0.09
Valencia	-1.72	-1.68	-1.82	-1.81	-0.09	-1.81	-1.79	-0.07
Merida	-1.66	-1.74	-1.78	-1.94	-0.29	-1.99	-1.89	-0.23
Seville	-1.63	-1.81	-2.04	-2.06	-0.43	-2.09	-1.89	-0.26
Pamplona	-1.69	-1.70	-2.14	-2.12	-0.43	-1.99	-2.08	-0.39
Logroño	-1.81	-1.92	-2.11	-2.10	-0.30	-1.98	-2.00	-0.20
Valladolid	-1.70	-1.86	-2.03	-2.35	-0.66	-2.00	-1.90	-0.21
Madrid	-1.91	-1.92	-2.09	-2.14	-0.23	-2.05	-2.03	-0.12
Toledo	-1.90	-2.11	-2.00	-1.95	-0.04	-1.95	-2.05	-0.15
Bilbao	0.00	0.00	-1.94	-1.97	-1.97↑	-1.98	-2.01	-2.01↑
Vitoria	-1.92	-1.99	-2.01	-2.01	-0.09	-2.01	-1.99	-0.07
Murcia	-1.59	-1.75	-1.76	-1.94	-0.35	-1.94	-1.92	-0.33
Barcelona	0.00	0.00	-2.03	-1.96	-1.96↑	-2.06	-1.94	-1.94↑

<i>Porto</i>	0.00	0.00	-1.94	-2.07	-2.07↑	-2.02	-1.90	-1.90↑
<i>Aveiro</i>	-0.26	-0.28	-1.96	-2.12	-1.85↑	-1.99	-1.90	-1.64↑
<i>Bragança</i>	-1.60	-1.66	-1.83	-2.07	-0.47	-1.81	-1.83	-0.23
<i>Guarda</i>	-1.73	-1.95	-1.79	-1.87	-0.14	-1.80	-1.72	0.02
<i>Coimbra</i>	-1.73	-1.91	-1.97	-2.10	-0.37	-1.90	-1.95	-0.22
<i>Castelo Branco</i>	-1.65	-1.92	-2.02	-2.37	-0.72	-1.98	-1.87	-0.22
<i>Santarém</i>	-1.75	-1.91	-1.99	-2.04	-0.29	-2.04	-1.93	-0.17
<i>Lisbon</i>	0.00	0.00	-1.95	-2.01	-2.01↑	-2.13	-2.00	-2.00↑
<i>Evora</i>	-1.75	-1.87	-1.98	-2.21	-0.46	-2.04	-1.92	-0.17
<i>Beja</i>	-1.69	-1.85	-2.05	-1.93	-0.25	-2.05	-1.90	-0.21
<i>Faro</i>	-0.15	-0.16	-2.14	-2.22	-2.06↑	-2.06	-1.86	-1.71↑

As previously carried out for the duration and intensity, the frequency of occurrence of both 12m-WASP intermediate-to-severe wet and dry for the IP main cities, under both RCPs, are analysed (Table S3). The results show that most of the anomalies range from -6.34 to 6.87 , for the probability of occurrence of intermediate-to-severe wet events in certain cities. Depending on the location, this hints at either a small increase or decrease of wet events of already small percentages in the past periods. For Valencia (-6.31 and -6.26%), Seville (-6.14 and -7.18%), Logroño (-6.63 and -5.64%), Madrid (-2.67 and -5.09%) and Murcia (-5.68 and -5.8%) negative anomalies are projected under RCP4.5 and RCP8.5, respectively, while positive anomalies are found for Merida (3.38 and 3.55%), Toledo (3.7 and 2.2%) and Barcelona (4.17 and 3.31%), in Spain, Lisbon (6.37 and 4.2%), Faro (5.71 and 1.46%) Porto (2.64 and 4.77%) and Guarda (3.75 and 3.35%), in Portugal. In fact, it is worth mentioning that predictions for most of the Portuguese cities reveal positive anomalies for intermediate-to-severe wet events onto 2070, except for Bragança (-0.45 and -0.61%), Coimbra (-0.63 and 0.9%), and Beja (1.34 and -2.63%), under RCP4.5 and RCP8.5, respectively.

The results project higher positive anomalies for the intermediate-to-severe dry events over most of the cities (Table S3). Higher percentages are projected for Bilbao (15.8 and 20.72%), Seville (11.19 and 12.3%), Vitoria (11.85 and 10.46%), Pamplona (11.92 and 9.63%), and Madrid (9.83 and 10.91%) under RCP4.5 and RCP8.5, respectively, for Spanish cities and Porto (11.7 and 8.17%), Santarém (9.29 and 10.92%), Lisbon (9.62 and 11.35%), Évora (7.06 and 10.55%), Beja (7.77 and 11.99%) and Faro (9.35 and 18.05%) for Portuguese cities.

Table S3. Probability of occurrence (in %) of wet (dry) intermediate-to-severe events for the historical periods 1961–1990 and 1981–2010 and, 2021–2050 and 2041–2070 under RCP4.5 and RCP8.5 for the main IP cities (note that $\Delta(41-70 - 61-90)$).

Wet events			RCP4.5			RCP8.5		
City	1961–1990	1981–2010	2021–2050	2041–2070	Δ	2021–2050	2041–2070	Δ
Oviedo	2.11	0.37	1.36	1.49	-0.62	5.49	5.34	3.23
Santiago de Compostela	6.06	2.77	2.90	0.45	-5.61	2.10	5.29	-0.77
Zaragoza	6.81	5.97	3.20	5.70	-1.11	2.79	2.85	-3.96
Valencia	6.90	5.30	4.88	0.56	-6.34	4.34	0.64	-6.26
Merida	3.32	4.39	4.48	6.70	3.38	2.74	6.87	3.55
Seville	8.84	6.11	1.22	2.70	-6.14	3.04	1.65	-7.18
Pamplona	1.88	0.95	2.70	2.65	0.77	0.68	0.55	-1.33
Logroño	7.51	2.32	0.76	0.88	-6.63	3.04	1.87	-5.64
Valladolid	2.68	4.68	2.60	4.10	1.41	0.41	3.73	1.05
Madrid	6.63	0.88	2.75	3.96	-2.67	0.92	1.54	-5.09
Toledo	2.92	3.39	2.52	6.61	3.70	2.12	5.12	2.20
Bilbao	0.00	0.00	0.42	1.67	1.67	3.35	4.65	4.65
Vitoria	4.26	0.10	0.28	1.31	-2.96	1.82	1.79	-2.48
Murcia	6.49	4.78	1.95	0.81	-5.68	0.61	0.68	-5.80
Barcelona	0.00	0.00	2.74	4.17	4.17	2.28	3.31	3.31
<i>Porto</i>	0.00	0.00	2.64	2.64	2.64	1.10	4.77	4.77
<i>Aveiro</i>	0.77	0.32	2.92	2.92	2.15	0.42	5.05	4.29
<i>Bragança</i>	4.08	4.52	4.48	3.63	-0.45	1.27	3.47	-0.61
<i>Guarda</i>	2.93	0.00	4.64	6.68	3.75	1.47	6.28	3.35
<i>Coimbra</i>	4.82	2.02	4.19	4.19	-0.63	1.05	5.71	0.90
<i>Castelo Branco</i>	3.63	1.85	5.47	6.18	2.55	1.20	5.05	1.42
<i>Santarem</i>	4.40	8.75	5.80	5.82	1.43	1.20	5.43	1.03
<i>Lisbon</i>	0.00	0.00	6.20	6.87	6.87	1.91	4.20	4.20
<i>Évora</i>	5.02	3.84	4.19	6.07	1.05	0.81	5.47	0.45
<i>Beja</i>	6.51	8.37	5.00	7.50	0.98	1.34	3.88	-2.63
<i>Faro</i>	0.64	0.51	5.34	6.34	5.71	1.36	2.10	1.46
Dry events			RCP4.5			RCP8.5		
City	1961–1990	1981–2010	2021–2050	2041–2070	Δ	2021–2050	2041–2070	Δ
Oviedo	1.39	2.36	16.09	7.59	6.20	2.49	8.71	7.33
Santiago de Compostela	4.72	7.68	8.02	6.65	1.93	4.62	5.35	0.63
Zaragoza	1.34	4.09	6.90	8.14	6.80	11.23	3.61	2.27
Valencia	2.13	0.54	4.44	9.66	7.53	2.81	3.50	1.36
Merida	1.15	7.77	6.56	5.89	4.74	14.39	8.70	7.55
Seville	0.79	6.73	11.19	11.98	11.19↑	13.87	13.09	12.30↑
Pamplona	1.98	3.55	9.89	13.90	11.92↑	10.70	11.61	9.63
Logroño	2.69	4.54	11.30	10.31	7.62	6.27	9.17	6.48
Valladolid	2.49	5.83	14.27	7.19	4.71	12.17	8.58	6.09
Madrid	3.83	10.24	11.15	13.66	9.83	15.76	14.73	10.91
Toledo	2.55	9.55	9.69	14.66	12.11↑	15.03	12.36	9.81
Bilbao	0.00	0.00	16.22	15.80	15.80↑	5.85	20.72	20.72↑
Vitoria	4.87	10.60	17.07	16.72	11.85↑	5.95	15.33	10.46↑
Murcia	1.85	2.38	6.58	13.19	11.33↑	7.21	9.36	7.51
Barcelona	0.00	0.00	9.58	11.18	11.18↑	7.63	4.59	4.59

<i>Porto</i>	0.00	0.00	14.35	11.70	11.70↑	8.16	8.17	8.17
<i>Aveiro</i>	0.28	1.65	11.58	9.60	9.32	9.47	6.30	6.02
<i>Bragança</i>	1.59	1.04	8.49	8.68	7.09	6.30	10.51	8.92
<i>Guarda</i>	4.35	17.25	7.07	7.80	3.46	8.08	6.83	2.48
<i>Coimbra</i>	1.91	9.86	11.48	7.97	6.06	11.40	6.89	4.98
<i>Castelo Branco</i>	4.35	10.49	10.52	6.69	2.34	13.43	10.97	6.62
<i>Santarem</i>	1.12	4.16	8.73	10.41	9.29	14.59	12.03	10.92↑
<i>Lisbon</i>	0.00	0.00	11.85	9.62	9.62	14.78	11.35	11.35↑
<i>Évora</i>	1.52	9.22	10.27	8.58	7.06	15.60	12.08	10.55↑
<i>Beja</i>	3.07	7.46	10.62	10.84	7.77	15.02	15.06	11.99↑
<i>Faro</i>	0.47	1.01	12.29	9.82	9.35	17.85	18.52	18.05↑