Sub-hourly precipitation extremes in mainland Portugal and their driving mechanisms

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Supplemental Material

Table S1. List of the selected 71 weather stations (WS) in mainland Portugal. Their codes, name, latitude, longitude, and elevation (meters above mean sea level) are shown. The start and end years of the available data by weather station are also listed (end years for currently operational stations are indicated by -). The corresponding percentages of missing data in the 10-minute precipitation over the recording period are also provided. Stations with surface pressure records are highlighted in their codes with *. Data source: IPMA.

Code	Weather station name	Latitude (ºN)	Longitude (ºW)	Elevation (m AMSL)	Start year	End year	Missing data (%)
531*	Cabo Carvoeiro	39.361	9.406	32	2000	-	81
533*	Sagres	37.012	8.949	25	2000	-	73
535*	Lisboa Geofísico	38.719	9.149	77	2009	2014	5
541*	Sines Monte	37.954	8.838	103	2000	2006	1
542*	Sines Cabo	37.957	8.887	19	2000	-	85
543*	Viana do Castelo	41.706	8.802	16	2009	-	71
545*	Porto Pedras Rubras	41.233	8.681	63	2000	-	5
546*	Porto Serra Pilar	41.138	8.602	93	2006	-	72
548*	Coimbra Aeródromo	40.156	8.467	170	2000	-	2
551*	Viana do Castelo	41.648	8.804	48	2002	2010	31
554*	Faro Aeroporto	37.016	7.971	8	2002	2014	11
555*	Faro	37.018	7.921	32	2000	-	68
557*	Évora	38.572	7.906	309	2000	-	56
558*	Évora CC	38.536	7.887	246	2000	-	4
560*	Viseu CC	40.714	7.895	636	2010	-	1
562*	Beja	38.024	7.867	246	2000	-	5
566*	Vila Real	41.308	7.74	481	2000	-	54
567*	Vila Real CC	41.274	7.717	561	2000	-	0
568*	Penhas Douradas	40.411	7.558	1380	2000	-	8
570*	Castelo Branco	39.839	7.478	449	2000	-	3
571*	Portalegre	39.294	7.421	597	2000	-	2
575*	Bragança	41.803	6.742	690	2000	-	5
577*	Odemira S. Teotónio	37.525	8.754	76	2000	-	10
579*	Lisboa Gago Coutinho	38.766	9.128	104	2000	-	1
604	Geres Carris	41.750	8.033	1480	2000	-	22
605	Geres	41.733	8.150	370	2000	-	20
606	Lamas de Mouro	42.033	8.183	880	2000	-	24
611	Montalegre	41.822	7.787	1005	2000	-	12
615	Ponte de Lima	41.763	8.571	40	2000	-	15
616	Chaves Aeródromo	41.725	7.465	360	2000	-	2
619	Cabril	41.716	8.016	585	2000	-	11
622	Braga Merelim	41.575	8.451	65	2000	-	10
630	Cabeceiras de Basto	41.533	7.966	350	2001	-	18
632	Mirandela	41.514	7.190	250	2000	-	10
633	Macedo de Cavaleiros	41.567	6.787	702	2000	-	22
635	Miranda do Douro	41.498	6.271	693	2002	-	6

Table S1. (*Continuation*)

637	Mogadouro	41.333	6.724	644	2002	-	10
644	Carrazeda de Ansiães	41.233	7.283	715	2000	-	22
654	Moncorvo	41.189	7.018	600	2000	-	17
666	Trancoso Bandarra	40.780	7.351	850	2000	-	22
671	Figueira Cast Rodrigo	40.830	6.940	635	2000	-	13
683	Guarda	40.528	7.278	1020	2000	-	11
685	Nelas	40.523	7.855	425	2000	-	10
687*	Covilhã Aeródromo	40.264	7.482	482	2019	-	22
697	Lousã Aeródromo	40.143	8.244	195	2000	-	11
704	Dunas de Mira	40.446	8.761	14	2019	-	91
705	Anadia	40.439	8.440	45	2019	-	9
707	Coimbra	40.213	8.455	35	2019	-	95
713	Figueira da Foz	40.140	8.806	4	2019	-	91
716	Ansião	39.898	8.410	396	2019	-	91
718	Leiria	39.781	8.821	45	2019	-	91
721	São Pedro de Moel	39.764	9.031	40	2019	-	92
746	Santa Cruz	39.126	9.379	40	2019	-	95
750	Cabo da Roca	38.782	9.498	141	2019	-	91
762	Lisboa Ajuda	38.710	9.183	69	2019	-	91
767	Pegões	38.651	8.635	64	2019	-	91
773	Almada	38.617	9.213	5	2019	-	91
788	Zambujeira	37.582	8.743	67	2000	-	91
790	Fóia	37.314	8.596	895	2000	-	93
800	Sabugal	40.339	7.036	858	2000	-	14
803	Zebreira	39.866	7.016	375	2000	-	13
806	Proença-a-Nova	39.728	7.870	379	2000	-	13
812	Alvega	39.461	8.026	51	2000	-	9
824	Avis Benavila	39.106	7.877	150	2000	-	11
835	Elvas	38.889	7.140	208	2000	-	5
837	Estremoz	38.862	7.512	366	2000	-	13
863	Mértola Vale Formoso	37.757	7.551	190	2000	-	7
865	Alcoutim Martim	37.437	7.768	290	2000	2016	17
867	Castro Marim	37.229	7.425	5	2000	-	5
868	Almodôvar	37.400	8.083	400	2000	-	48
878*	Portimão Aeródromo	37.147	8.583	14	2000	-	6

Table S2. List of mesohigh episodes related to SHHP events for synoptic-type RegL, with the year, month, day, and 10-minute occurrence (chronological order). The weather station (WS) code is also indicated.

Year	Month	Day	Hour	Minutes	WS code
2000	5	1	13	30	562
2000	5	10	13	50	575
2000	5	20	22	0	575
2001	5	9	13	30	543
2001	7	30	17	0	570
2002	6	19	2	30	575
2003	8	10	15	50	570
2003	11	15	10	20	554
2006	6	14	0	30	562
2006	7	14	19	0	571
2007	9	14	18	30	571
2008	6	16	15	20	560
2010	4	16	10	10	554
2010	4	21	21	30	560
2011	4	21	17	40	558
2011	5	20	14	40	560
2014	7	2	15	20	570
2014	9	27	14	40	548
2014	10	13	17	10	558
2014	11	27	21	40	535
2015	6	14	14	0	570
2017	6	17	17	20	570
2017	8	29	16	10	558
2018	4	21	6	10	878
2018	5	20	17	0	687
2018	6	21	17	30	541
2020	7	21	18	40	558

Table S3. List of mesohigh episodes related to SHHP events for synoptic-type RemL, with the year, month, day, and 10-minute occurrence (chronological order). The weather station (WS) code is also indicated.

Year	Month	Day	Hour	Minutes	WS code
2000	5	11	16	30	571
2000	5	22	15	20	560
2001	2	6	12	10	535
2001	2	6	12	10	579
2001	10	20	11	40	570
2002	1	21	12	40	543
2002	10	29	20	0	535
2002	10	29	20	30	560
2002	11	13	11	20	545
2002	11	13	12	20	560
2002	11	13	14	20	571
2002	11	20	20	0	543
2003	10	30	23	10	560
2003	10	31	2	40	579
2003	10	31	2	50	535
2003	10	31	2	50	571
2004	8	16	14	30	571
2004	10	20	9	50	575
2006	10	22	22	10	562
2006	10	23	3	40	562
2006	10	25	2	40	562
2006	10	25	3	10	558
2006	11	24	17	0	535
2007	11	19	22	10	554
2008	1	3	1	20	579
2008	1	3	1	30	535
2008	1	3	3	20	562
2008	4	18	1	20	554
2009	6	15	15	30	579
2009	10	20	9	0	535
2009	11	13	22	20	545
2009	12	23	2	40	878
2010	1	12	11	30	541
2010	9	20	14	0	571
2010	10	8	15	0	579
2011	2	13	9	10	551
2011	2	13	9	40	545
2011	2	16	3	10	545
2011	2	16	3	20	546
2011	9	1	13	0	562
2011	10	24	0	10	551

Table S3. (*Continuation*)

2011	11	2	11	40	570
2011	12	1	21	30	545
2013	10	22	3	0	541
2013	12	24	17	0	570
2016	1	10	5	10	545
2017	12	11	1	30	541
2018	1	13	12	0	548
2018	12	18	11	20	545
2019	12	19	21	40	535
2020	11	24	22	10	551

(a)	(b)
3 July 2000, 04:50 UTC, **32.6 mm**	31 October 2005, 09:30 UTC, **27.1 mm**
616: Chaves Aeródromo (+2 WS)	*557: Évora (+5 WS)*
(c)	(d)
11 April 2002, 17:40 UTC, **26.8 mm**	31 July 2020, 13:20 UTC, **26.6 mm**
557: Évora (+3 WS)	*707: Coimbra (+0 WS)*
(e)	(f)
20 October 2000, 14:30 UTC, **25.9 mm**	22 October 2006, 09:30 UTC, **25.9 mm**
616: Chaves Aeródromo (+3 WS)	*557: Évora (+16 WS)*
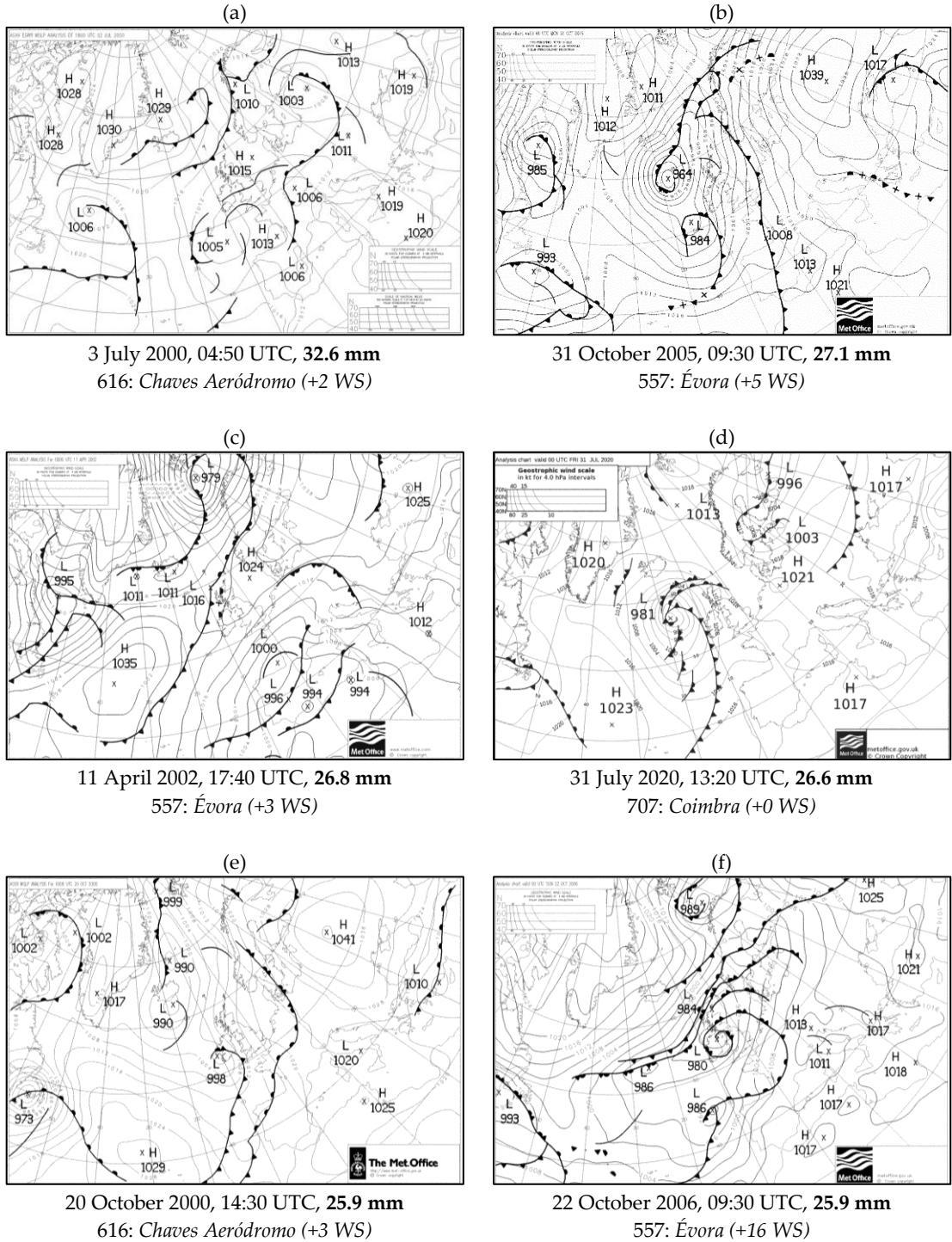
Figure S1. Synoptic analysis charts for the third-to-tenth severest SHHP events (10-minute precipitation ≥ 25 mm). The first two severest are shown in Figure 4. Source: Met Office (metoffice.gov.uk, accessed on 3 February 2022).

(g)

15 June 2006, 00:20 UTC, **25.1 mm**
605: *Gerês (+4 WS)*

(h)

7 November 2012, 22:10 UTC, **25.0 mm**
566: *Vila Real (+0 WS)*
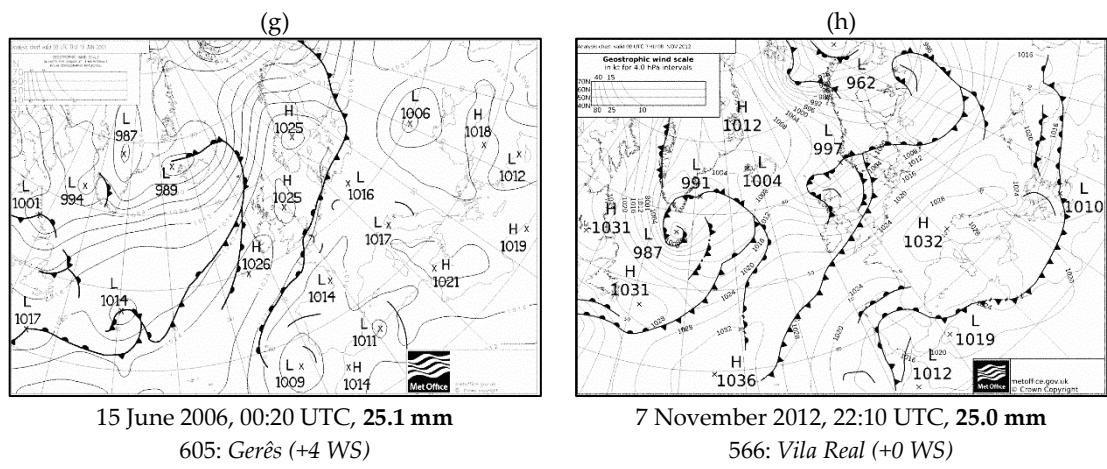
Figure S1. (*Continuation*).
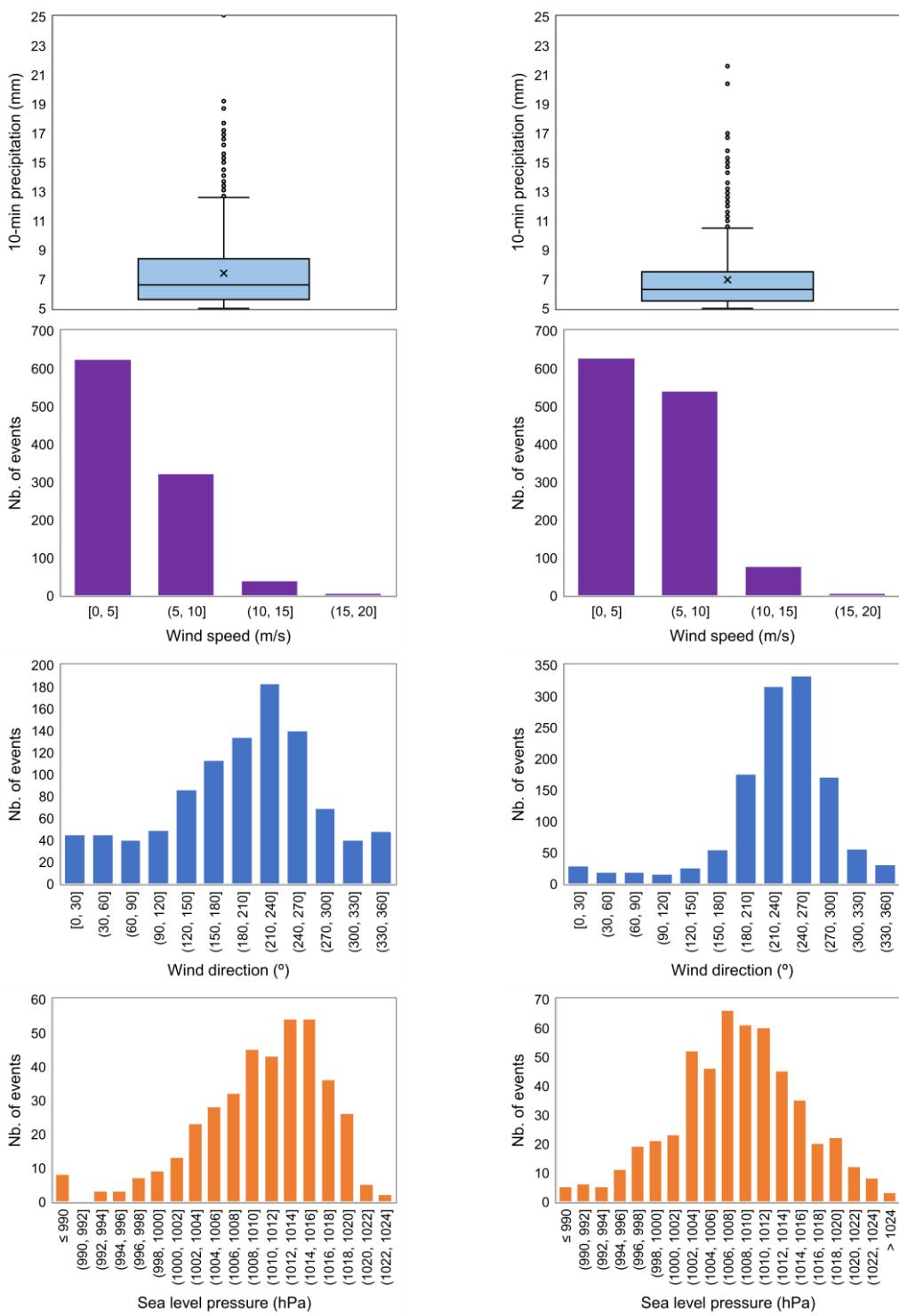
Figure S2. Distribution of the outlined atmospheric variables recorded at the weather stations at the occurrence of the sub-hourly extreme precipitation events and by class separately (*left panels*: RegL, *right panels*: RemL).
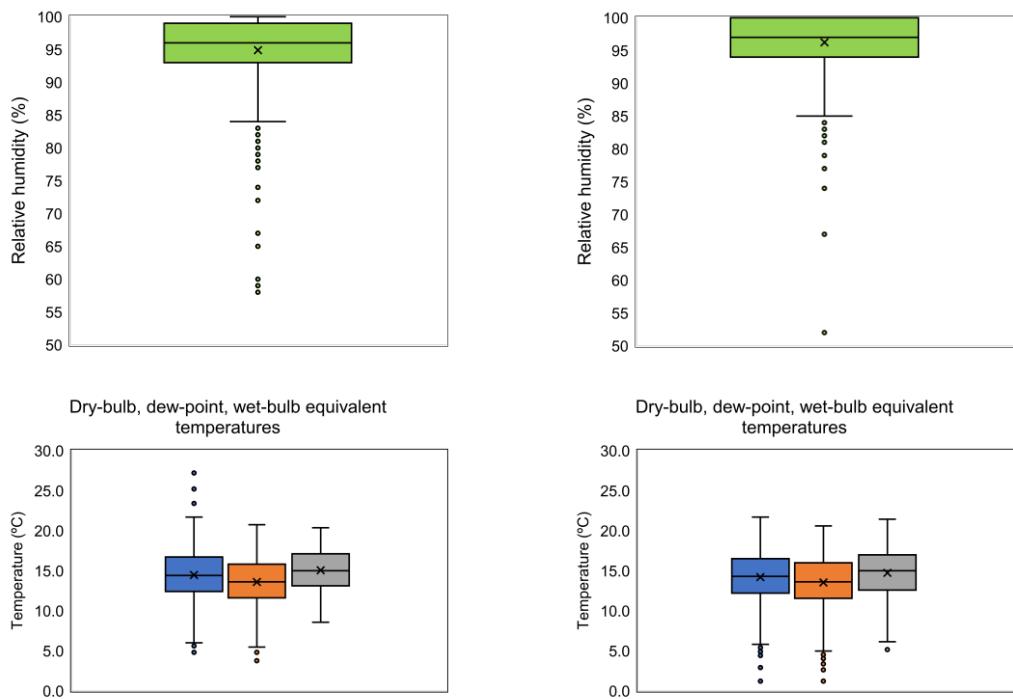
Figure S2. (*Continuation*).
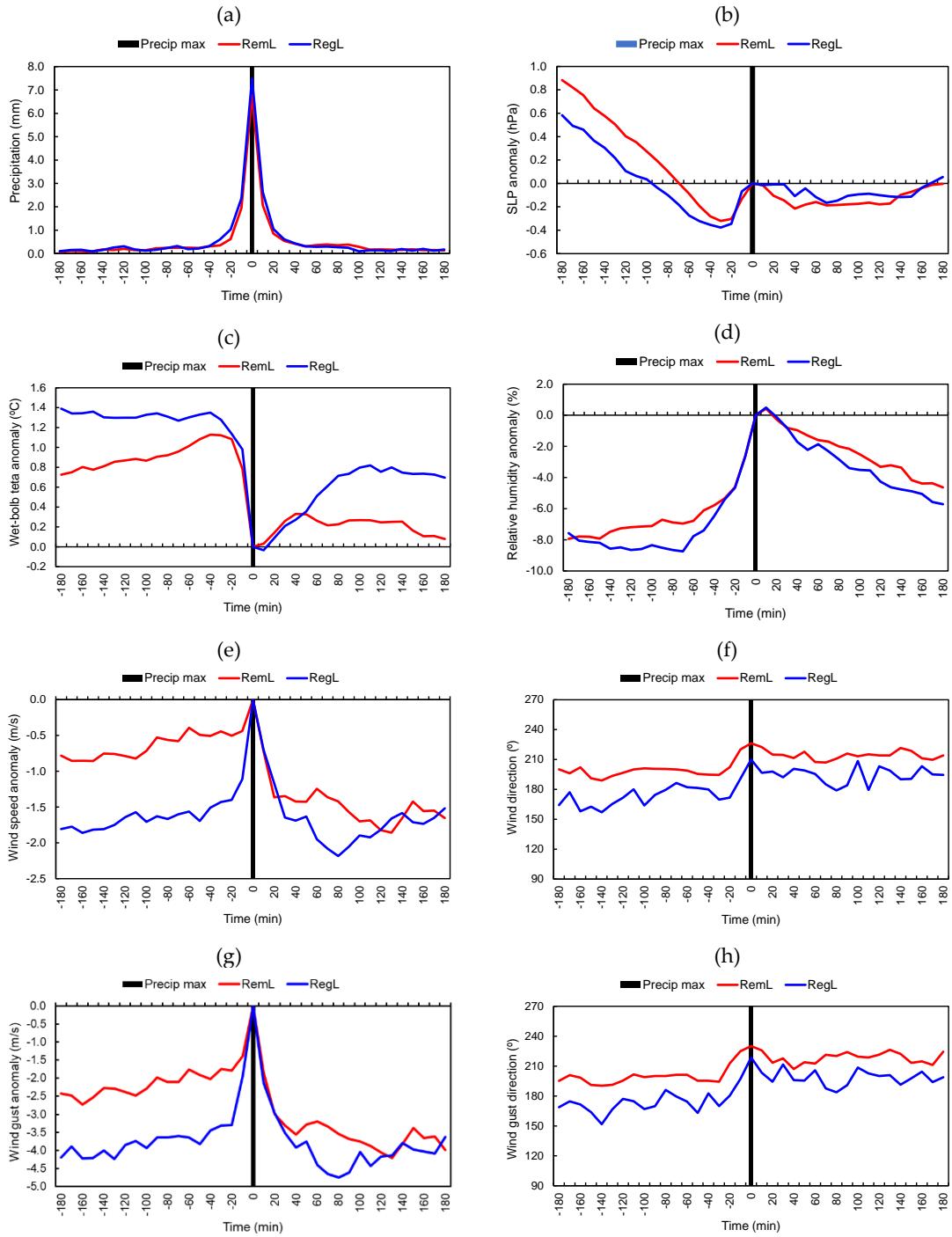
Figure S3. Mean chronological series over a 6-hour window centered at the instant of the event occurrences (87 events with 10-minute precipitation ≥ 5.0 mm, 35 RegL and 52 RemL), for the Lisbon weather station (579: *Lisboa Gago Coutinho*) and for: (a) precipitation, (b) sea level pressure anomaly (w. r. t. the event instant), (c) wet-bulb potential temperature anomaly, (d) relative humidity anomaly, (e) wind speed anomaly, (f) wind direction, (g) wind gust, (h) wind gust direction. The event occurrence is tracked with a vertical black line.
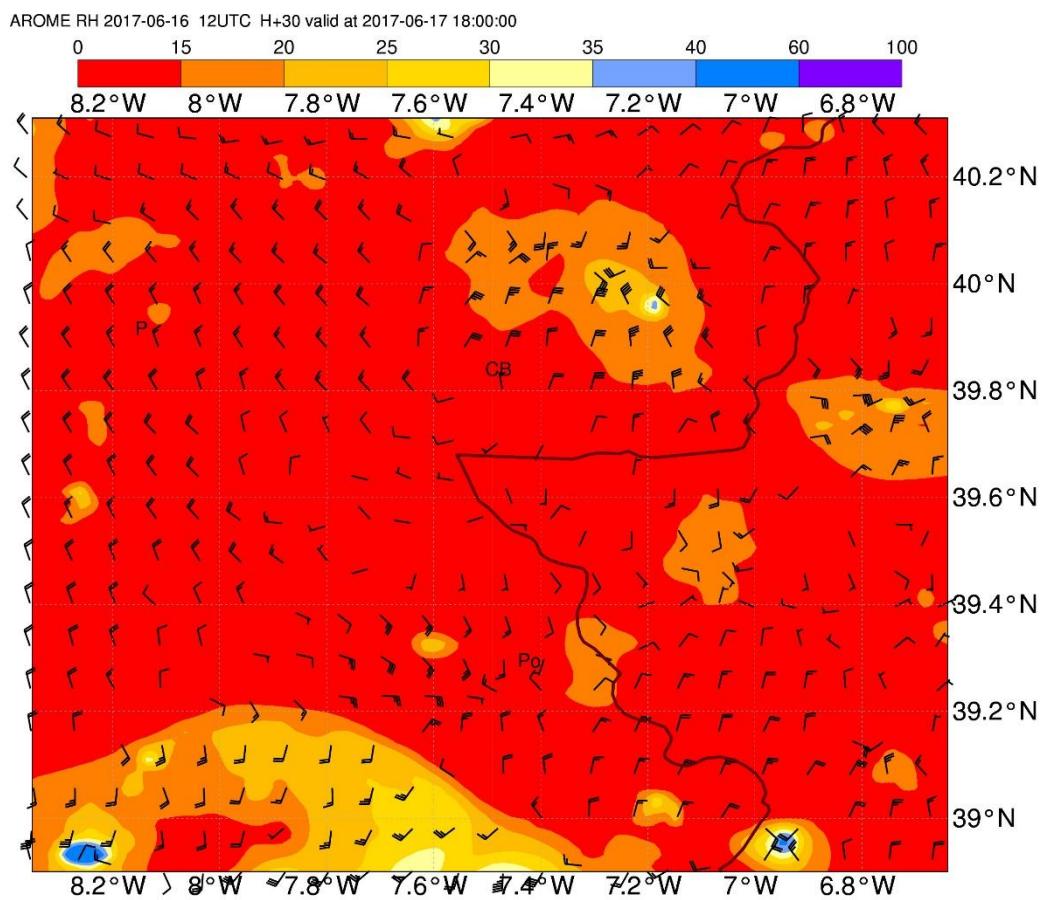
Figure S4. AROME forecast (H+30) of 2-m relative humidity (in %) on 17 June 2017, valid at 18:00 UTC.

BT 245 K████████████████████**205 K**
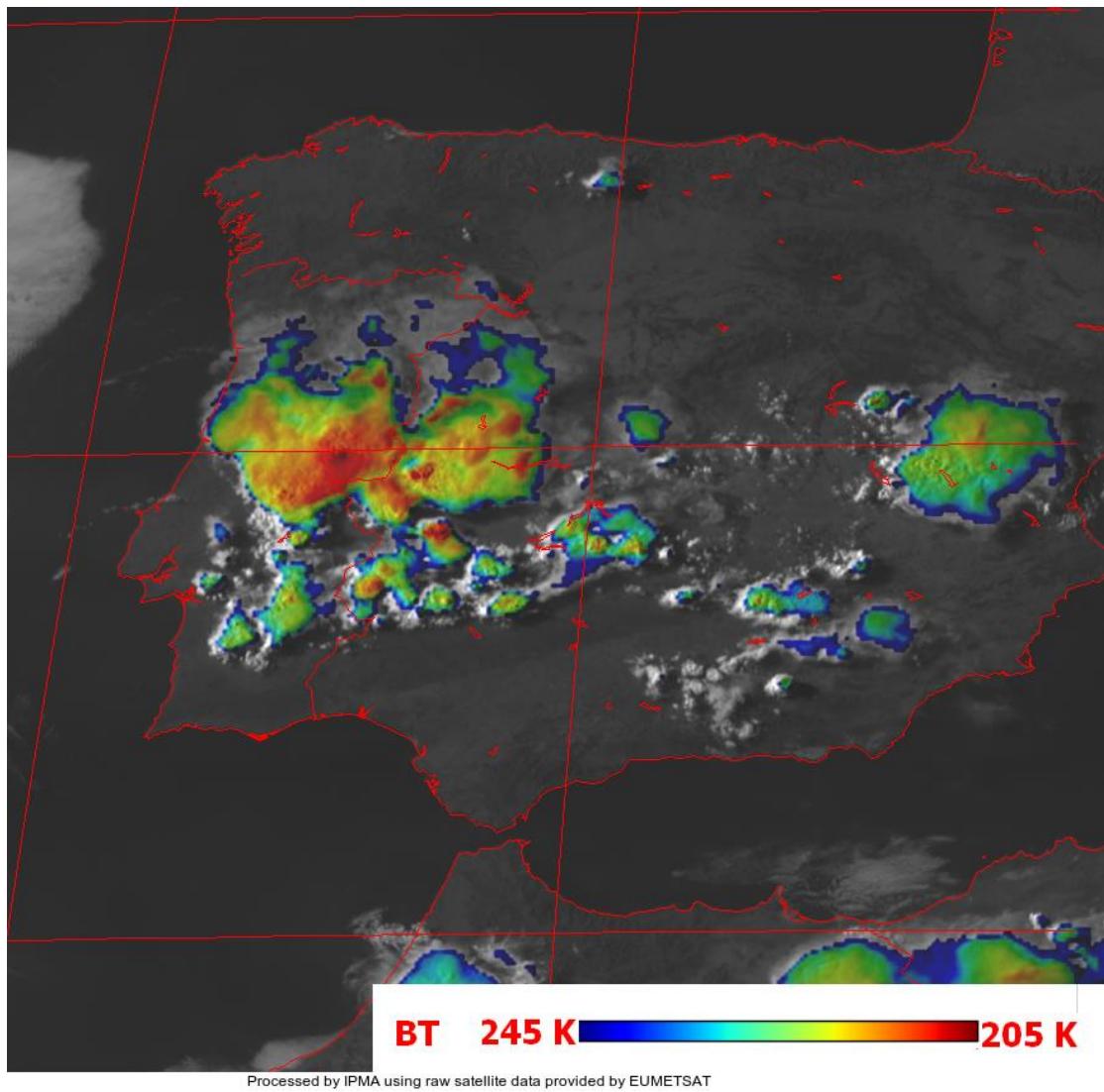
Figure S5. Satellite sandwich product on 17 June 2017, at 17:00 UTC. This product blends the High Resolution Visible (HRV) image (background) with color-enhanced IR10.8 image, showing the details of the cloud top temperature (in K).
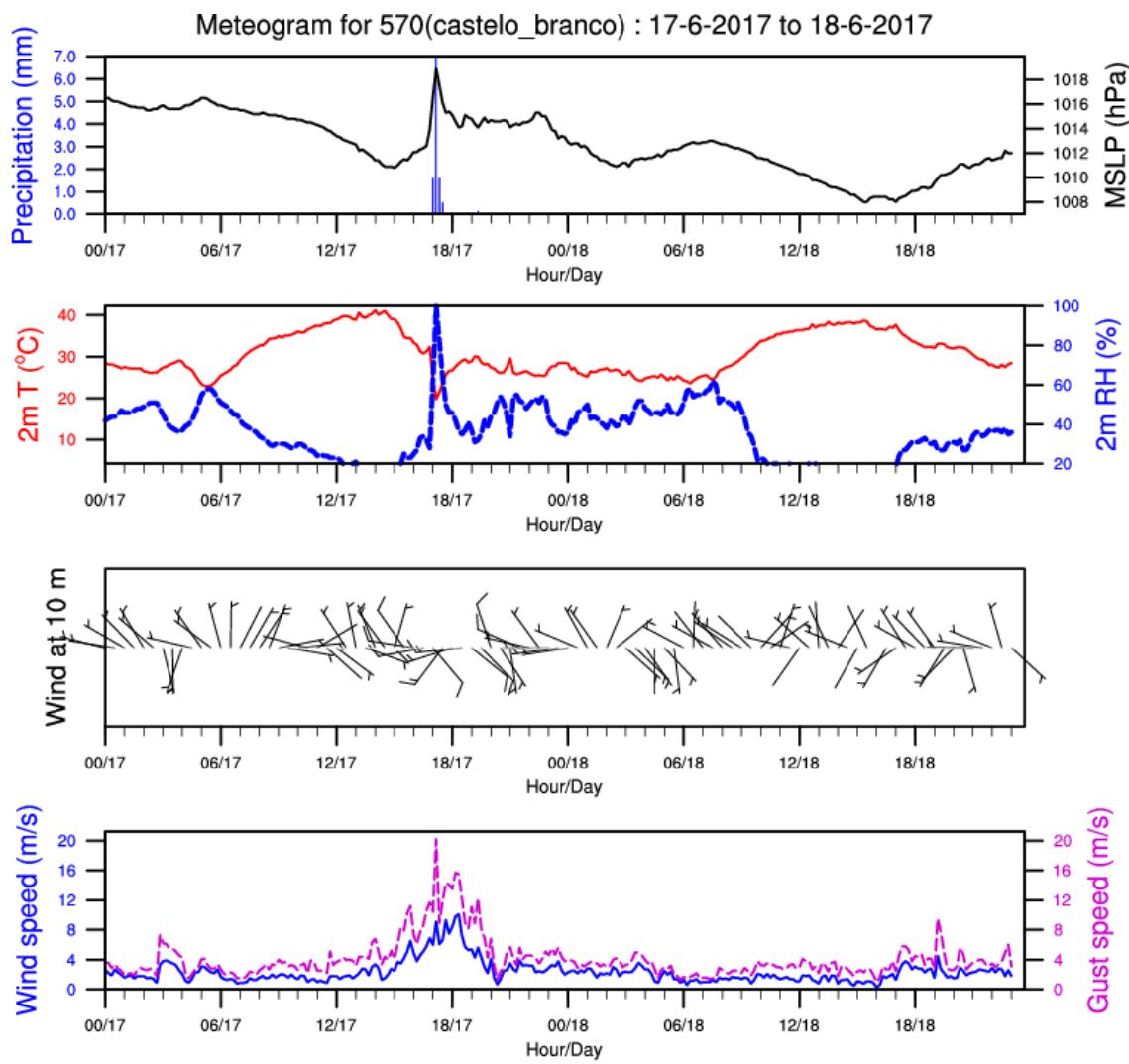
Figure S6. Meteogram based on the 10-minutes observations at the weather station 570 (*Castelo Branco*), on 17 and 18 June 2017.