ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

SCUOLA DI INGEGNERIA E ARCHITETTURA

CORSO DI LAUREA MAGISTRALE IN
INGEGNERIA PER L'AMBIENTE E IL TERRITORIO

WAVE CLIMATE IN THE SOUTHERN COAST OF MADEIRA ISLAND: ANNEX A

Tesi di laurea magistrale in Idraulica Marittima

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ANNEX A

Sommario

This paper presents analyses similar to those carried out in Chapter 2 concerning the characterisation of the wave climate off the island of Madeira. It is recalled that in the main document the analyses relating to the North West point have been presented. In this Annex A, the same analyses are presented, mainly using figures and tables, relating to the North, North East, South, and South West points.

NORTH POINT

North station is located at 33 degrees of latitude N and 343 degrees of longitude E (Figure 1)

Figure 1, Madeira Island, location of the North point.

For this point, to study Hs and Tp depending on their direction, they were divided into 8 direction classes.

Hs analyse

Figure 2 shows the polar diagram concerning Hs, where it can be seen that the majority of the waves in this point come from North and North West.

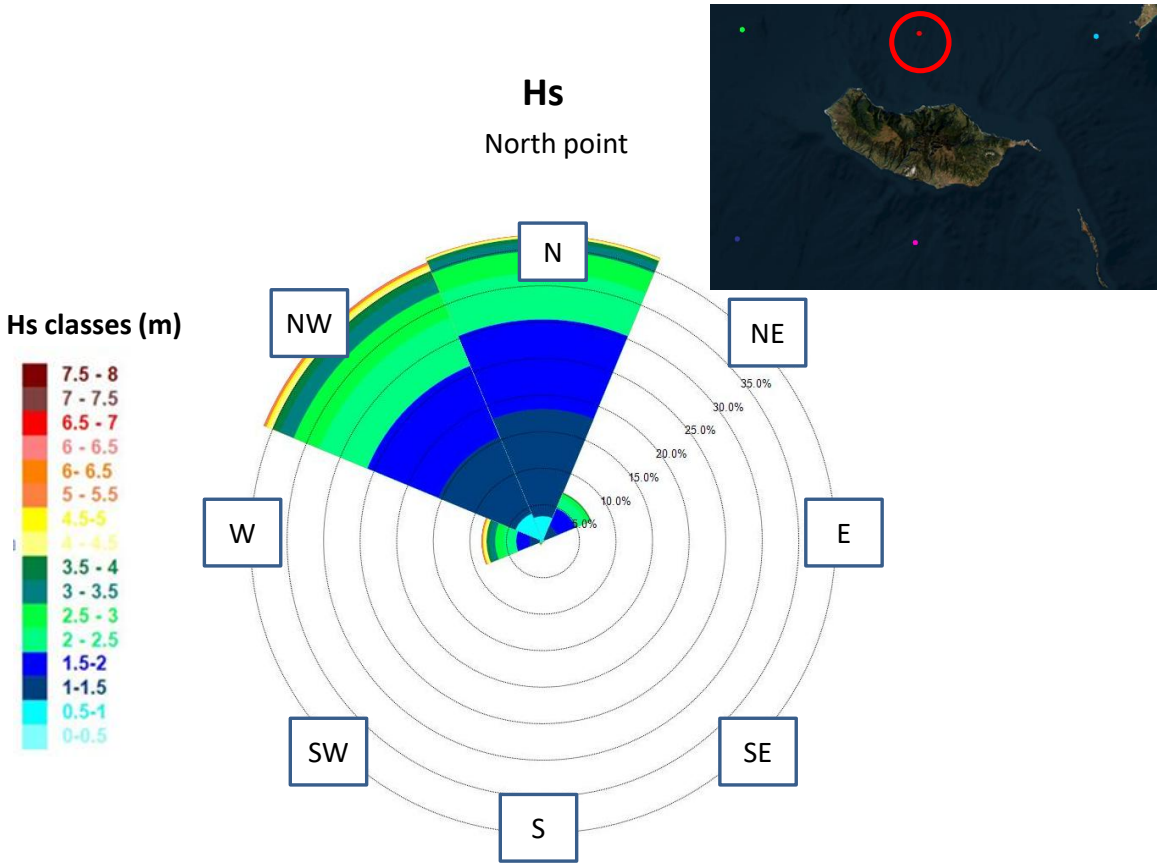


Figure 2, Polar diagram of Hs, North point.

The polar diagram of Figure 4 is also presented in Table 1, where it is possible to see that the most of the waves are less than 2/2.5 meters height, coming from North and North West.

Hs (m) / Dir(° N)	0-0,5	0,5-1	1-1,5	1,5-2	2-2,5	2,5-3	3-3,5	3,5-4	4-4,5	4,5-5	5-5,5	5,5-6	6-6,5	6,5-7	7-7,5	>7,5
0	4	4297	18525	15509	8013	3763	1612	690	283	125	50	23	18	3	3	0
45	0	331	2475	3373	1948	709	156	58	21	7	0	0	0	0	0	0
90	0	16	64	116	60	27	0	0	0	0	0	0	0	0	0	0
135	0	1	13	80	19	6	0	0	0	0	0	0	0	0	0	0
180	0	5	44	65	51	23	9	6	1	1	1	0	0	0	0	0
225	0	28	63	193	170	113	68	55	57	28	3	6	0	1	0	0

270	3	545	1756	2334	2147	1432	952	578	360	214	130	68	31	20	15	12
315	22	5097	14404	13307	8983	4730	2594	1402	725	389	244	119	78	35	16	19

Table 1, Number of sea states for each class of Hs and Dir based on the wave hindcast data provided by MetOceanView between 1/1/1979 and 4/1/1979 at 3-hour intervals at the North point.

Tp analyse

Figure 3 shows the Polar Diagram regarding Tp, with Table 2 that complements this by presenting the number of waves falling within specific Tp intervals. It is possible to observe that most values range from 8/9 to 13/14 seconds.

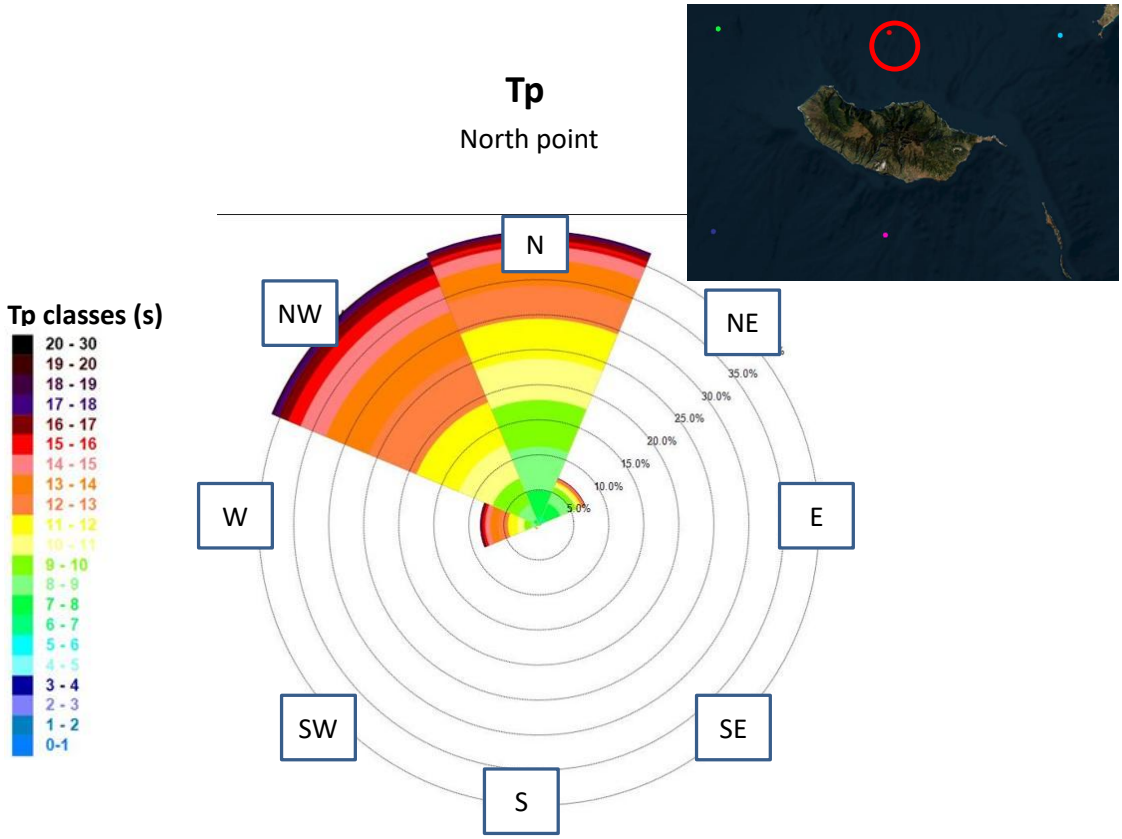


Figure 3, Polar Diagram for Tp, North point.

Tp Classes (s)	Counts
0 - 1	47
1 - 2	42366
2 - 3	74004
3 - 4	1
4 - 5	46
5 - 6	428
6 - 7	3121
7 - 8	8972
8 - 9	13909
9 - 10	15936
10 - 11	15915
11 - 12	17645

12 - 13	17440
13 - 14	14773
14 - 15	8231
15 - 16	4090
16 - 17	3497
17 - 18	1057
18 - 19	655
19 - 20	273
20 - 30	170
All data	126159

Table 2, wave count in Tp classes, North point.

Summer versus winter

Then, Figure 4 shows the comparison between Hs values in summer and in winter, where it is evident that both directions and Hs values change conspicuously.

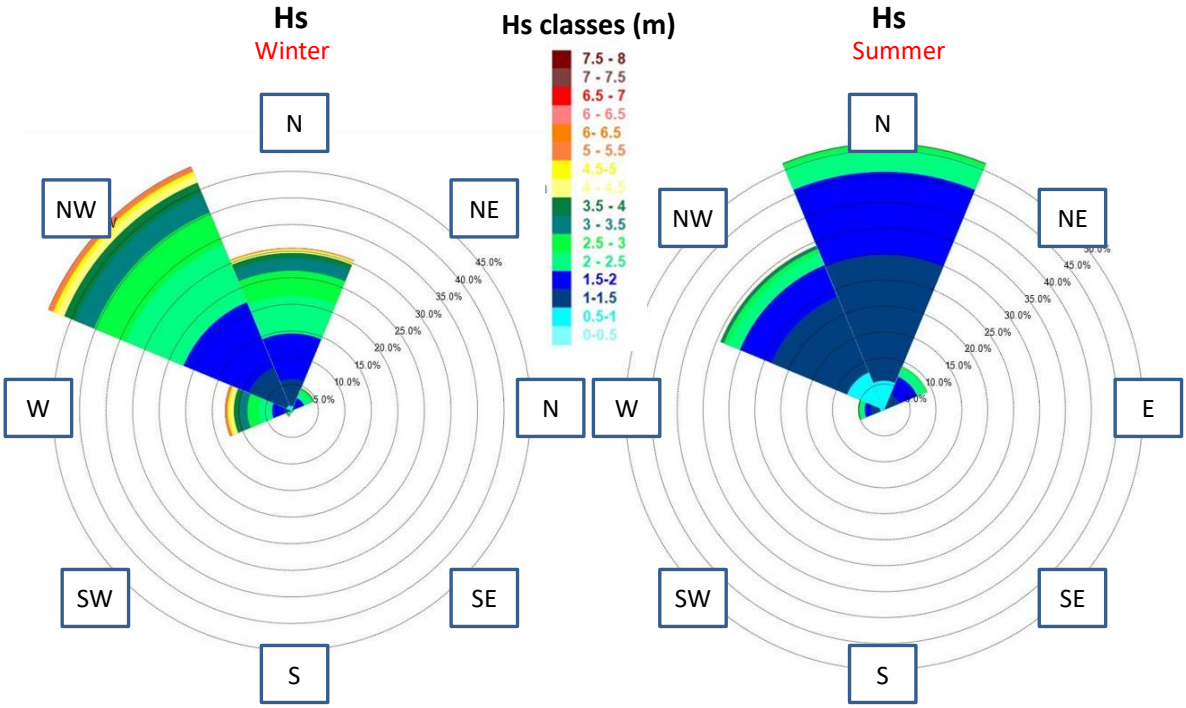


Figure 4, Comparison of Polar Diagram for Hs between Winter and Summer, North point

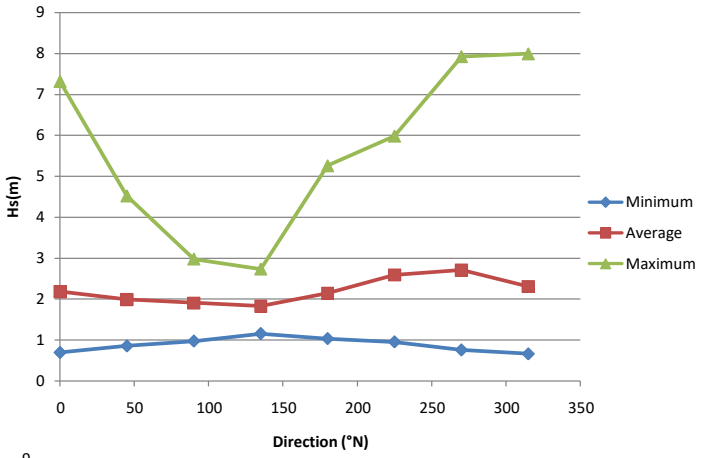
Finally, Figure 5 illustrates the graphs displaying the maximum, minimum, and average values for Hs during winter (Figure 5.a) and summer(Figure 5.b).

It is also possible to note how, if the values of Hs in summer are obviously lower, this season is characterized by less constancy in terms of maximum, average and minimum values.

Minimum, maximum and average Hs values for each direction

a) **WINTER**

Hs



b) **SUMMER**

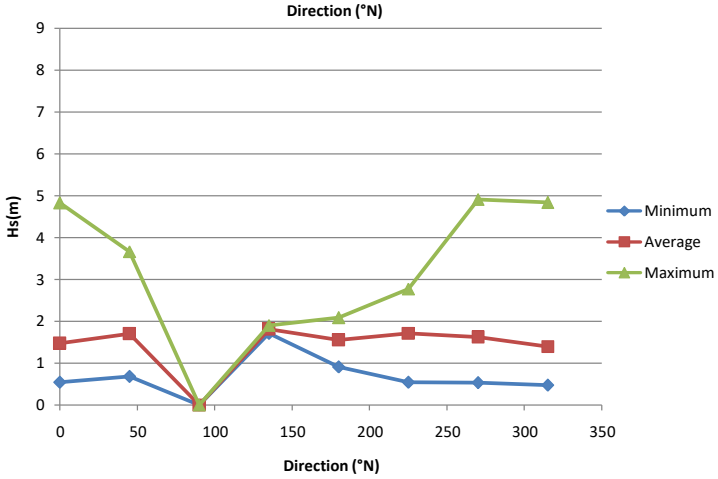


Figure 5, comparison of Polar Diagram for Tp between Winter and Summer, North point

NORTH EAST POINT

North east station is situated at 33 degrees of latitude North and 343.5 degrees of longitude East, Figure 6.

Figure 6, Madeira Island, location of the North East point.

Hs analyse

The main direction is clearly North, with also North West with a significant amount of values, with the maximum values that are equally distributed into the two directions, Figure 7.

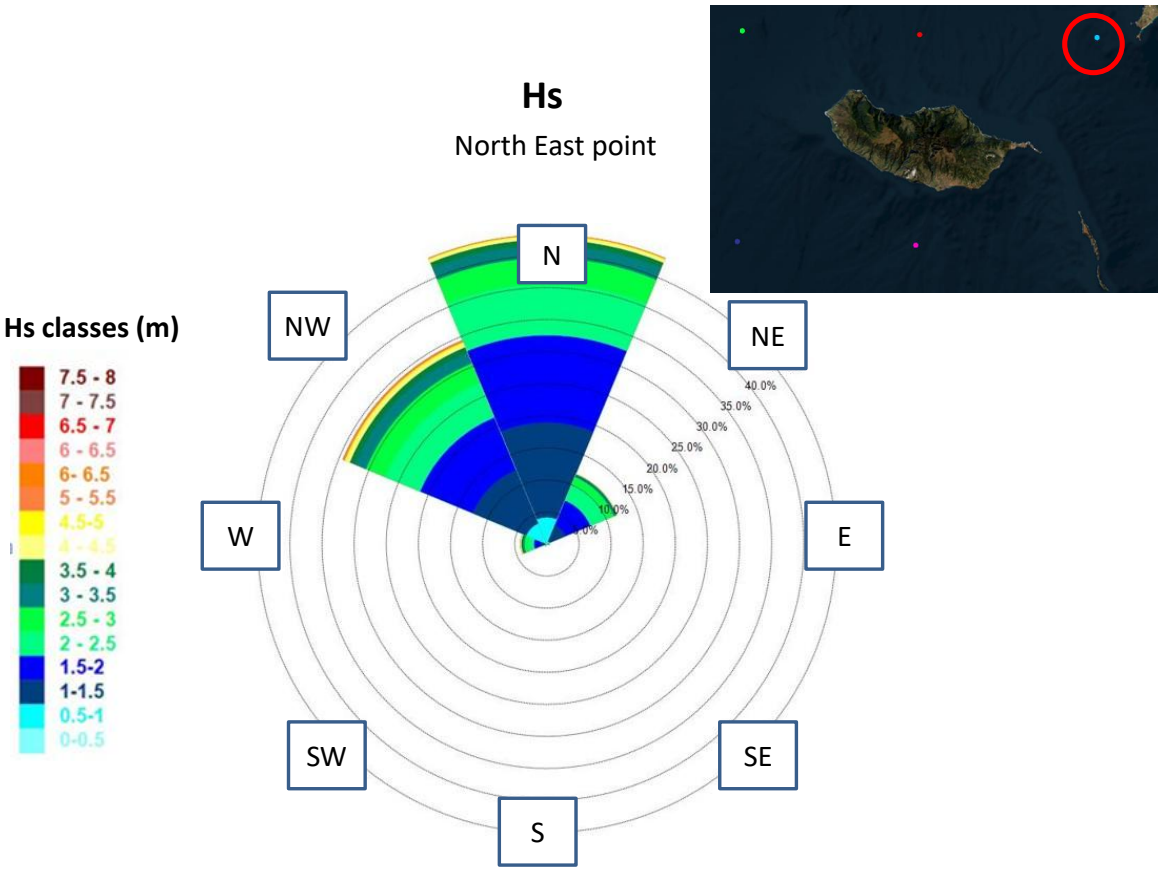


Figure 7, Polar diagram of Hs, North East point.

The main values for significant wave height is between 0,5 an 2,5 meters, with a constant decrease while going to bigger values, Table 3.

Hs (m) / Dir(°N)	0-0,5	0,5-1	1-1,5	1,5-2	2-2,5	2,5-3	3-3,5	3,5-4	4-4,5	4,5-5	5-5,5	5,5-6	6-6,5	6,5-7	7-7,5	>7,5
0	29	5184	18692	17177	10047	5107	2501	1161	537	248	104	50	28	13	3	2
45	0	526	3469	5287	3532	1446	491	148	48	36	5	0	0	0	0	0
90	0	10	135	238	125	57	14	6	2	3	0	0	0	0	0	0
135	0	1	48	104	56	27	9	4	0	0	0	0	0	0	0	0
180	0	2	23	73	73	48	16	6	4	1	0	0	0	0	0	0
225	0	5	75	149	112	69	79	23	8	3	0	0	0	0	0	0
270	2	185	1025	1336	1123	734	414	223	126	51	21	13	7	3	0	0

315	33	4302	11405	11242	7343	4125	2282	1199	688	353	200	122	65	26	20	10

Table 3, Number of sea states for each class of Hs and Dir based on the wave hindcast data by MetOceanView between 1/1/1979 and 4/1/1979 at 3-hour intervals at the North East point.

Tp analyse

As for the peak period values, the most of the values come between 7 and 14 seconds, with more values that are bigger than 14 rather than minor than 7, Figure 8 and Table 4.

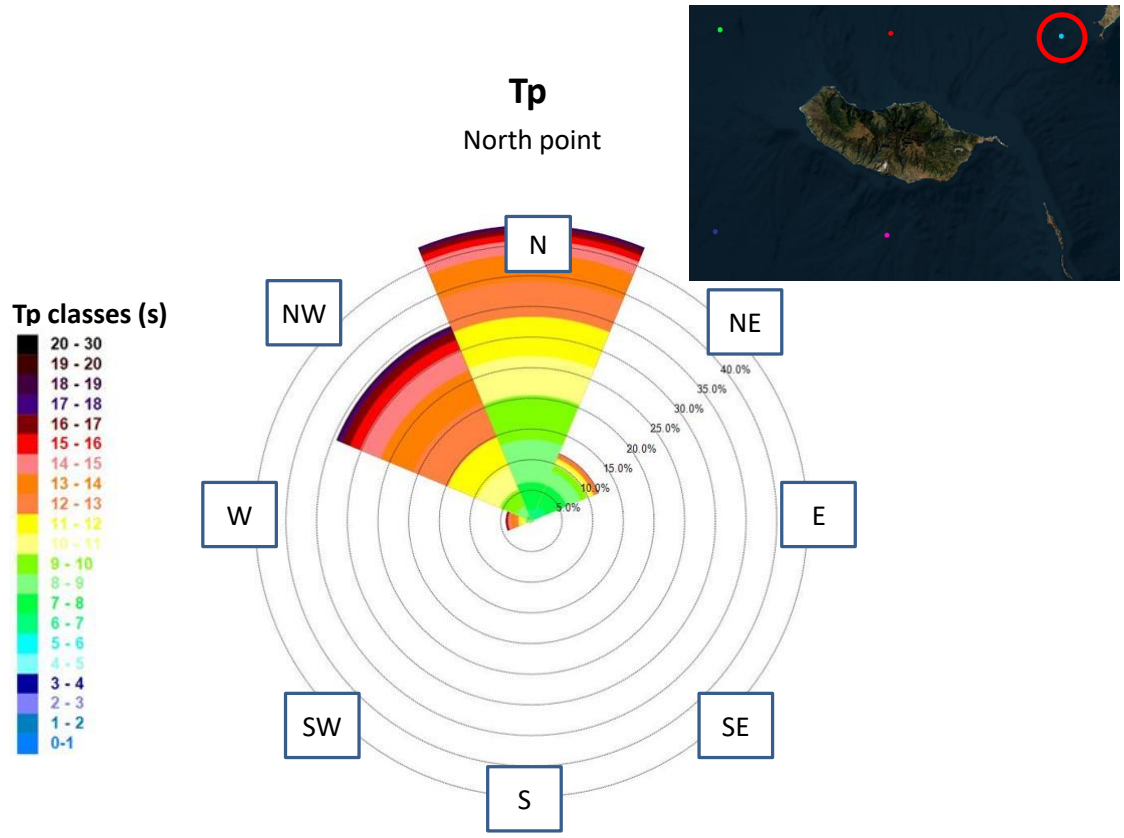


Figure 8, Polar Diagram for Tp, North East point.

Tp Classes (s)	Counts
0 - 1	33
1 - 2	4585
2 - 3	12551
3 - 4	6
4 - 5	68
5 - 6	879

6 - 7	5392
7 - 8	11639
8 - 9	14498
9 - 10	14979
10 - 11	14649
11 - 12	16300
12 - 13	16593
13 - 14	14025
14 - 15	7875
15 - 16	3947
16 - 17	3249
17 - 18	1083
18 - 19	591
19 - 20	254
20 - 30	132
All data	126159

Table 4, wave count in Tp classes, North East point.

Summer versus winter

In Figure 9 it is showed the comparison between winter and summer.

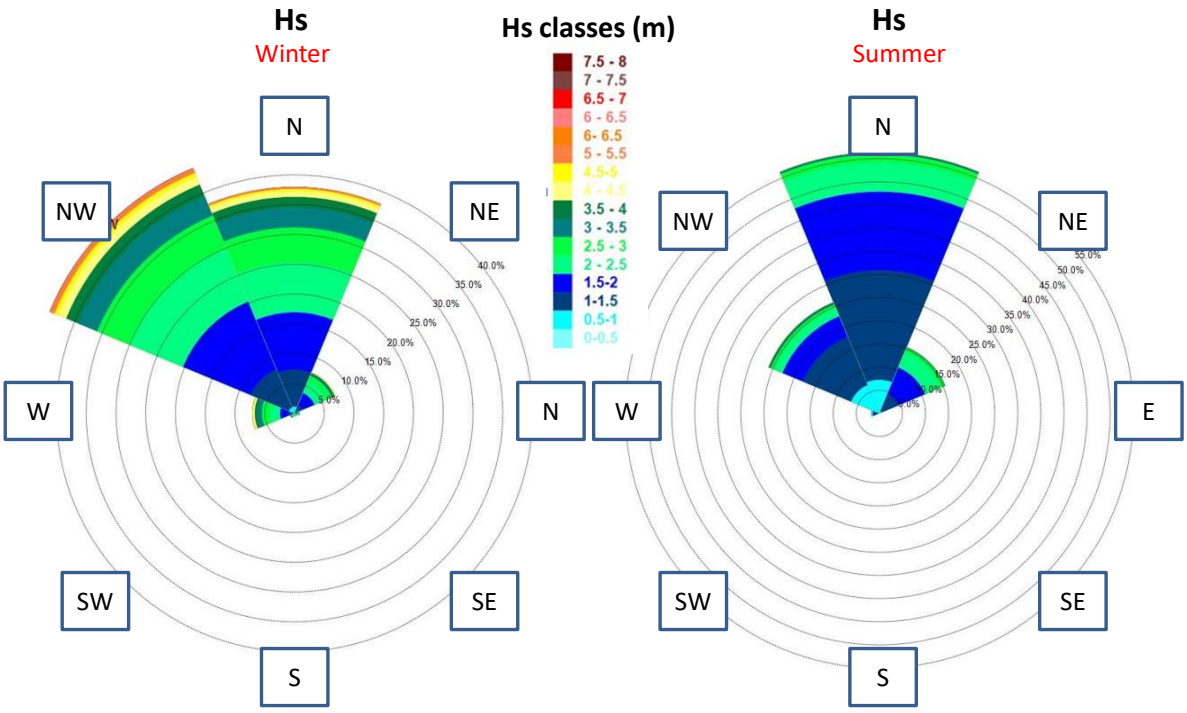


Figure 9, Comparison of Polar Diagram for Hs between Winter and Summer, North East point

In summer the waves are not so equally distributed between north west and north, as it happens for the overall data and also for winter, Figure 10.

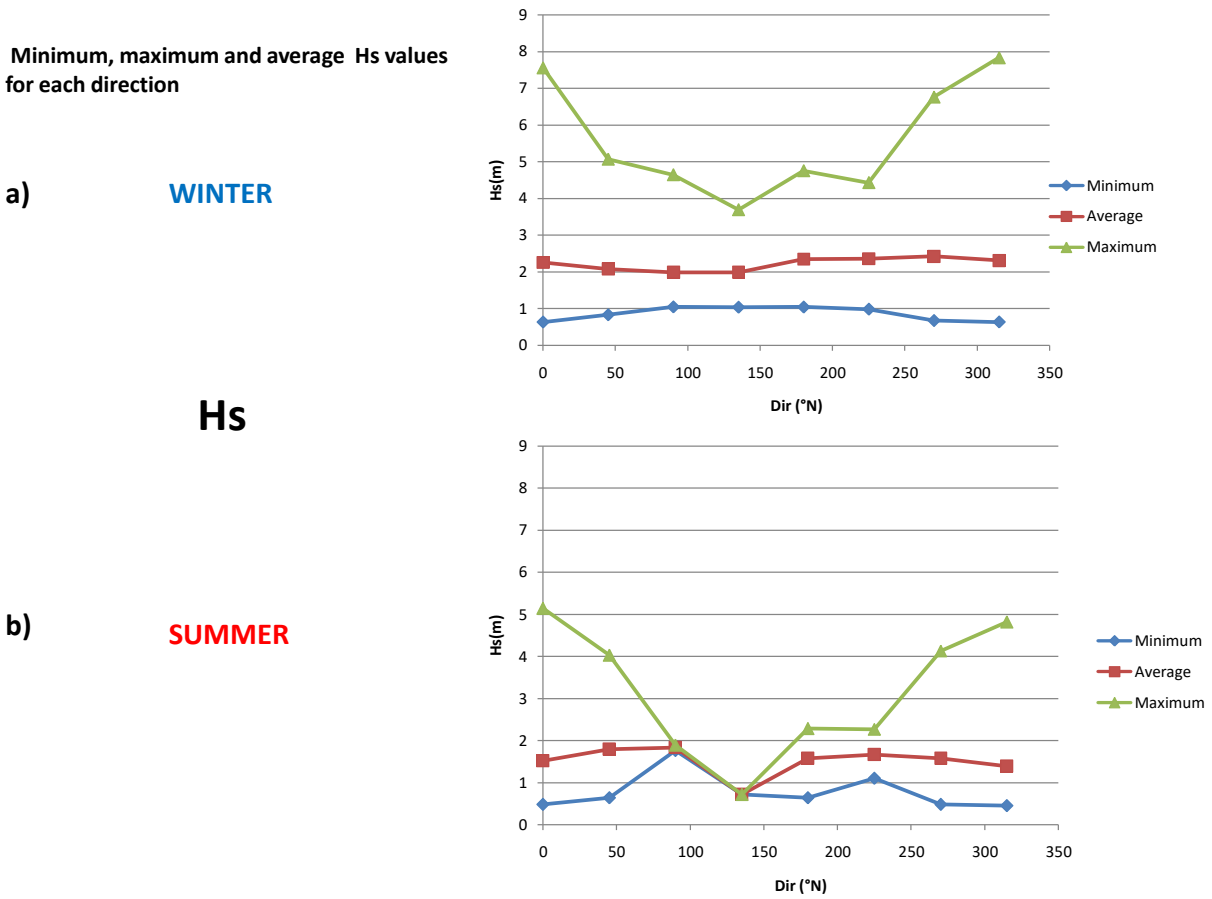


Figure 10, comparison of minimum, maximum, and average Hs values for each direction between: a) Winter; b) Summer. These graphs were generated as output following data processing by WindRosesPro, North East point.

Doing the same comparison with Peak period in the following tabs, reminding the previous confrontation, we can say that from winter to summer Tp values decrease even if the differences between maximum values are not as much evident as for Hs.

SOUTH POINT

The South point is located as shown in Figure 11.

Figure 11, Madeira Island, location of the South point.

Hs analyse

The vast majority of the waves comes from North West, with most of the values that goes from 0.5 to 2.5 meters, Figure 12 and Table 5.

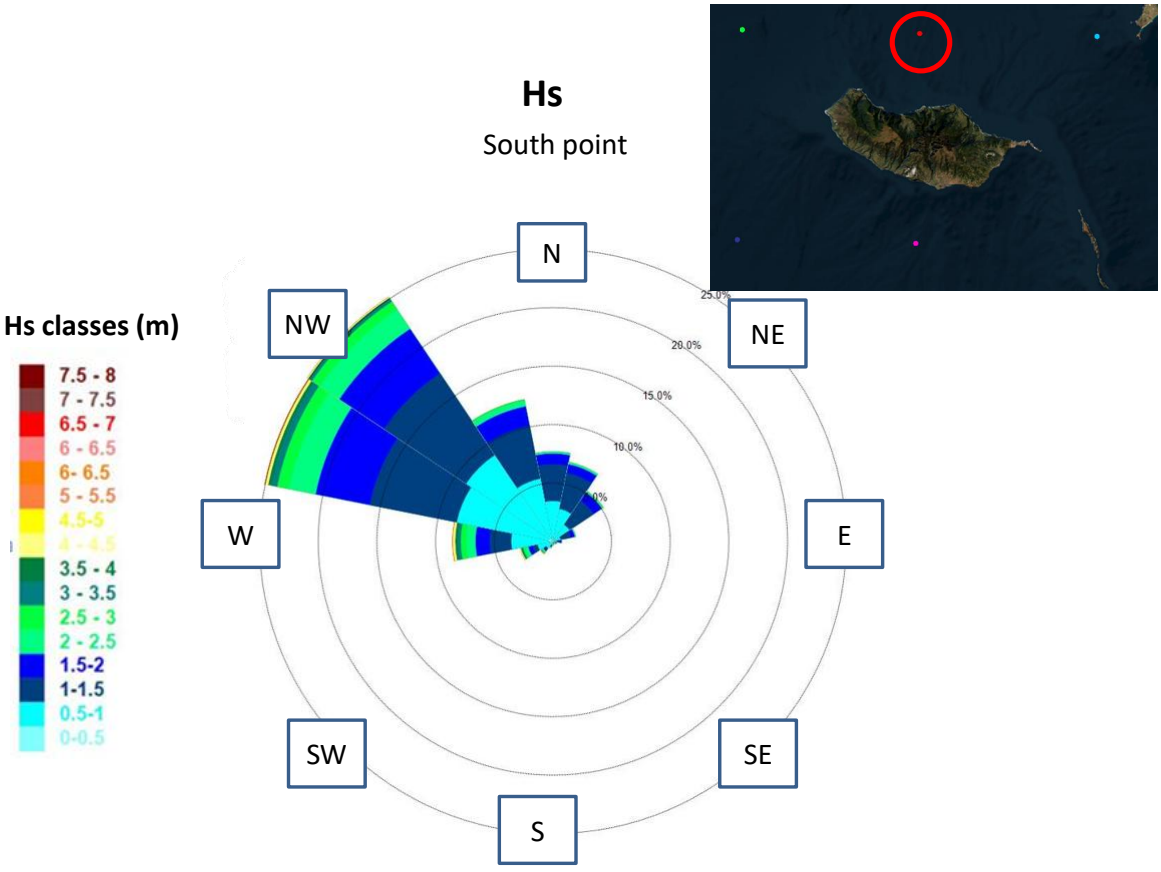


Figure 12, Polar diagram of Hs, South point.

	Hs (m)	0-0,5	0,5-1	1-1,5	1,5-2	2-2,5	2,5-3	3-3,5	3,5-4	4-4,5	4,5-5	5-5,5	5,5-6	6-6,5	6,5-7	7-7,5	>7,5
Dir(°N)																	
0		91	4250	3977	1172	190	25	13	3	1	1	0	0	0	0	0	0
22,5		48	3515	3975	976	190	30	4	3	1	0	0	0	0	0	0	0
45		35	2128	3130	1078	165	37	1	0	0	0	0	0	0	0	0	0
67,5		13	826	1129	463	104	6	0	0	0	0	0	0	0	0	0	0
90		6	364	396	174	52	6	3	0	0	0	0	0	0	0	0	0
112,5		9	173	153	96	44	8	0	0	2	0	0	0	0	0	0	0
135		8	109	123	98	36	7	3	1	1	0	0	0	0	0	0	0
157,5		11	104	90	96	32	7	0	0	0	0	0	0	0	0	0	0
180		6	141	93	104	44	27	13	2	1	0	1	0	0	0	0	0
202,5		59	329	127	113	63	38	12	10	10	2	4	1	0	0	0	0
225		164	724	214	190	139	91	55	30	20	31	6	2	1	1	0	0
247,5		209	1463	549	491	371	201	137	91	51	28	17	5	1	1	1	1
270		323	4142	2327	1541	957	609	381	227	158	87	36	15	9	5	4	1
292,5		489	10041	9547	5949	2911	1283	675	323	209	91	47	28	16	12	0	0
315		380	10830	10621	5801	2468	1038	357	147	79	29	21	7	5	0	0	0
337,5		227	6668	5839	2152	617	112	25	8	6	2	0	0	0	0	0	0

Table 5, Number of sea states for each class of Hs and Dir based on the wave hindcast data provided by MetOceanView between 1/1/1979 and 4/1/1979 at 3-hour intervals at the South point.

Tp analyse

With regard to Peak period, the most common values are the ones between 9-14 s, Figure 13 and Table 6.

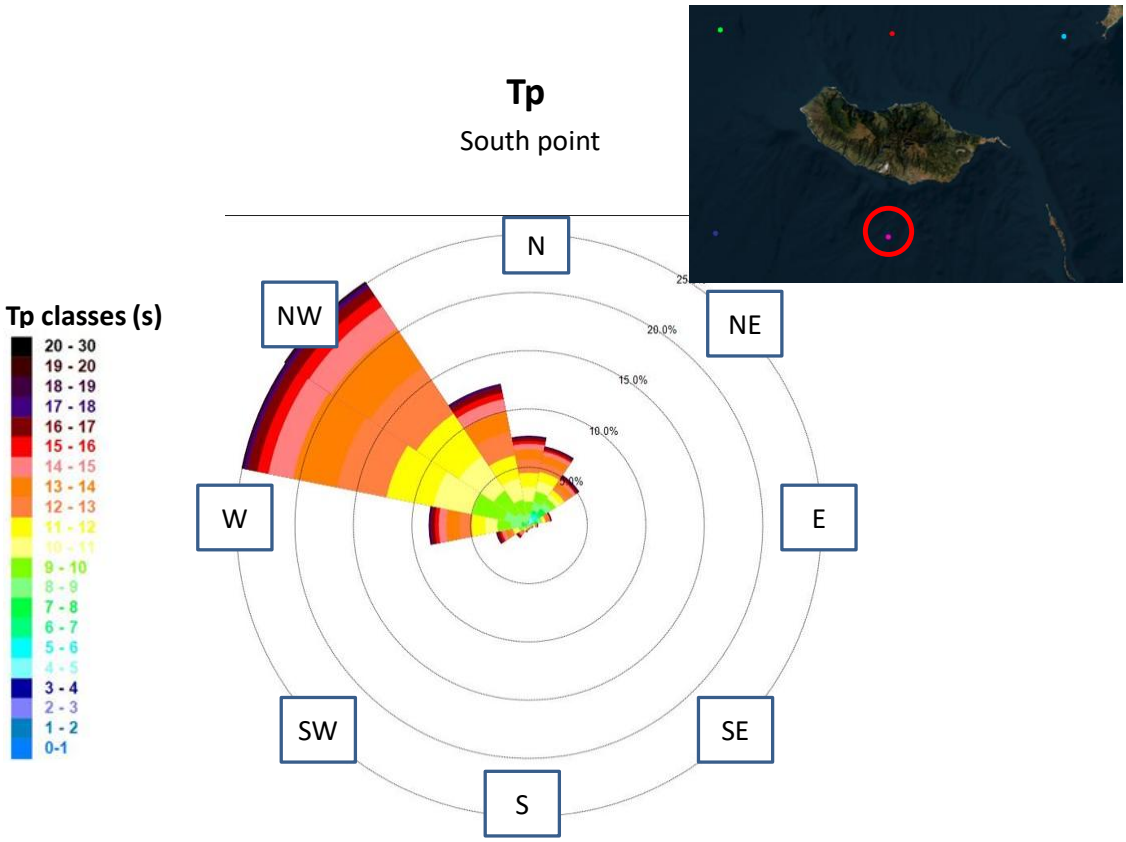


Figure 13, Polar Diagram for Tp, South point.

Tp classes (s)	Counts
0 – 1	848
1 – 2	16912
2 - 3	9872
3 - 4	195
4 - 5	1748
5 - 6	1802
6 - 7	2057
7 - 8	4051
8 - 9	8260
9 - 10	13547
10 - 11	16267

11 - 12	18663
12 - 13	19531
13 - 14	17269
14 - 15	9984
15 - 16	4967
16 - 17	4819
17 - 18	1217
18 - 19	1112
19 - 20	405
20 - 30	265
All data	126159

Table 6, wave count in Tp classes, South point.

Summer versus winter

Figure 14 shows the changes in terms of Hs in winter and summer in the comparison of the polar diagrams while Table 7 provides the maximum minimum and average Hs per each direction. As for the other points, winter Hs values are consistently bigger that summer. Also, the directional distribution is approximately the same, with the only difference that in summer more waves are able to arrive from the North East quadrant.

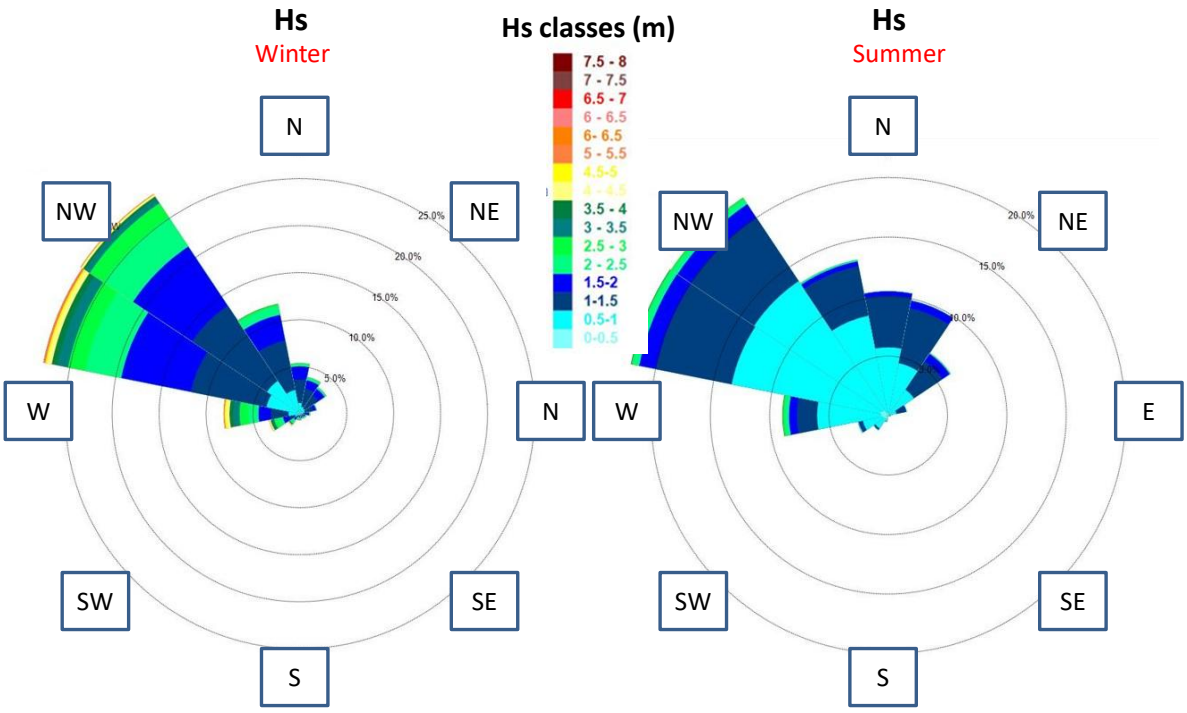


Figure 14, Comparison of Polar Diagram for Hs between Winter and Summer, South point

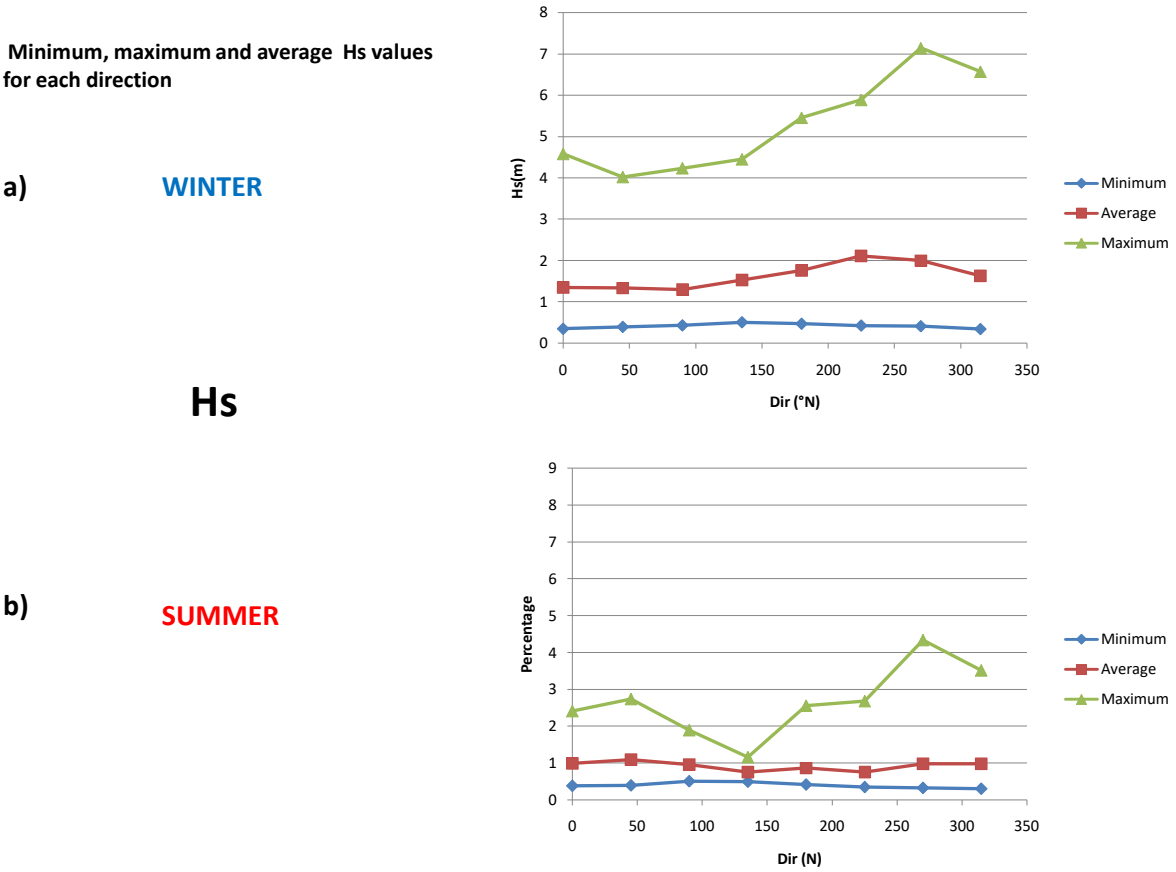


Figure 15, comparison of minimum, maximum, and average Hs values for each direction between: a) Winter; b) Summer. These graphs were generated as output following data processing by WindRosesPro, South point.

SOUTH WEST POINT

Figure 16 shows the location of the South West point.

Figure 16, Madeira Island, location of the South West point.

Hs analyse

Figure 17 shows that the vast majority of the waves comes from North West, with most of the values standing in the 1-2 m class, Table 7.

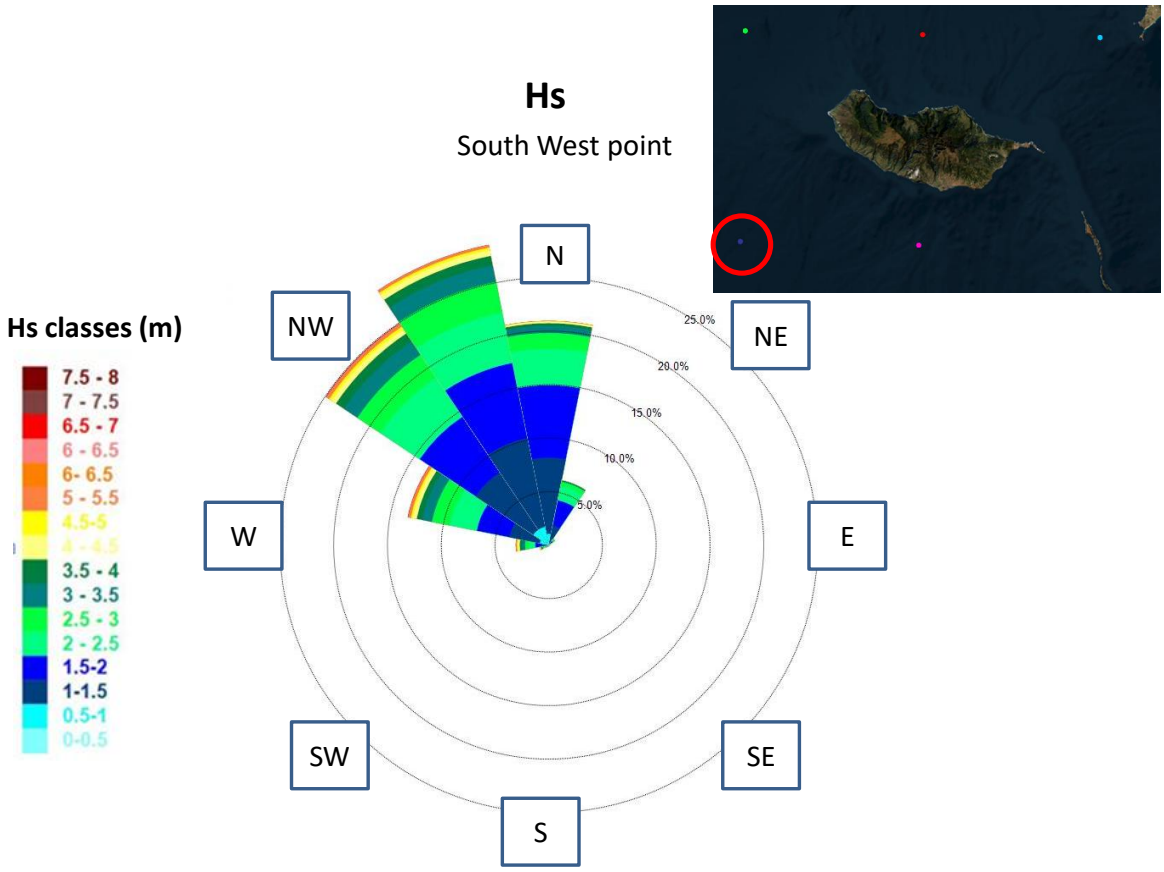


Figure 17, Polar diagram of Hs, South West point.

Hs (m) / Dir(°N)	0-0,5	0,5-1	1-1,5	1,5-2	2-2,5	2,5-3	3-3,5	3,5-4	4-4,5	4,5-5	5-5,5	5,5-6	6-6,5	6,5-7	7-7,5	>7,5
0	0	1312	8980	8565	4271	1869	845	327	149	71	23	6	10	4	1	1
22,5	0	208	2136	3058	1700	513	144	46	10	4	1	0	0	0	0	0
45	0	44	269	299	188	102	9	1	0	0	1	0	0	0	0	0
67,5	0	14	87	74	55	18	6	2	0	0	0	0	0	0	0	0
90	0	6	30	31	39	16	1	0	0	0	0	0	0	0	0	0

112,5	0	1	17	36	31	15	2	0	0	0	0	0	0	0	0	0
135	0	0	11	42	34	9	0	0	0	0	0	0	0	0	0	0
157,5	0	1	32	27	39	6	0	0	0	0	0	0	0	0	0	0
180	0	2	19	41	36	23	7	8	0	1	0	0	0	0	0	0
202,5	0	9	17	66	53	38	17	5	4	4	6	4	0	0	0	0
225	0	28	33	72	92	51	39	23	22	26	16	5	1	1	1	0
247,5	3	94	100	191	204	199	126	90	51	39	24	12	4	3	0	0
270	2	268	611	714	694	487	365	291	157	135	78	41	22	9	6	4
292,5	1	1068	3630	3932	3195	2149	1182	663	428	235	169	109	44	36	24	12
315	2	2166	8148	7910	5545	3229	1908	1134	581	352	198	120	88	54	24	19
337,5	0	2177	10651	9078	6040	3696	2010	1129	659	317	166	96	59	17	9	5

Table 7, Number of sea states for each class of Hs and Dir based on the wave hindcast data provided by MetOceanView between 1/1/1979 and 4/1/1979 at 3-hour intervals at the South West point.

Tp analyse

Figure 18 and Table 8 show that the most common values are the ones standing in the 11-12 s class.

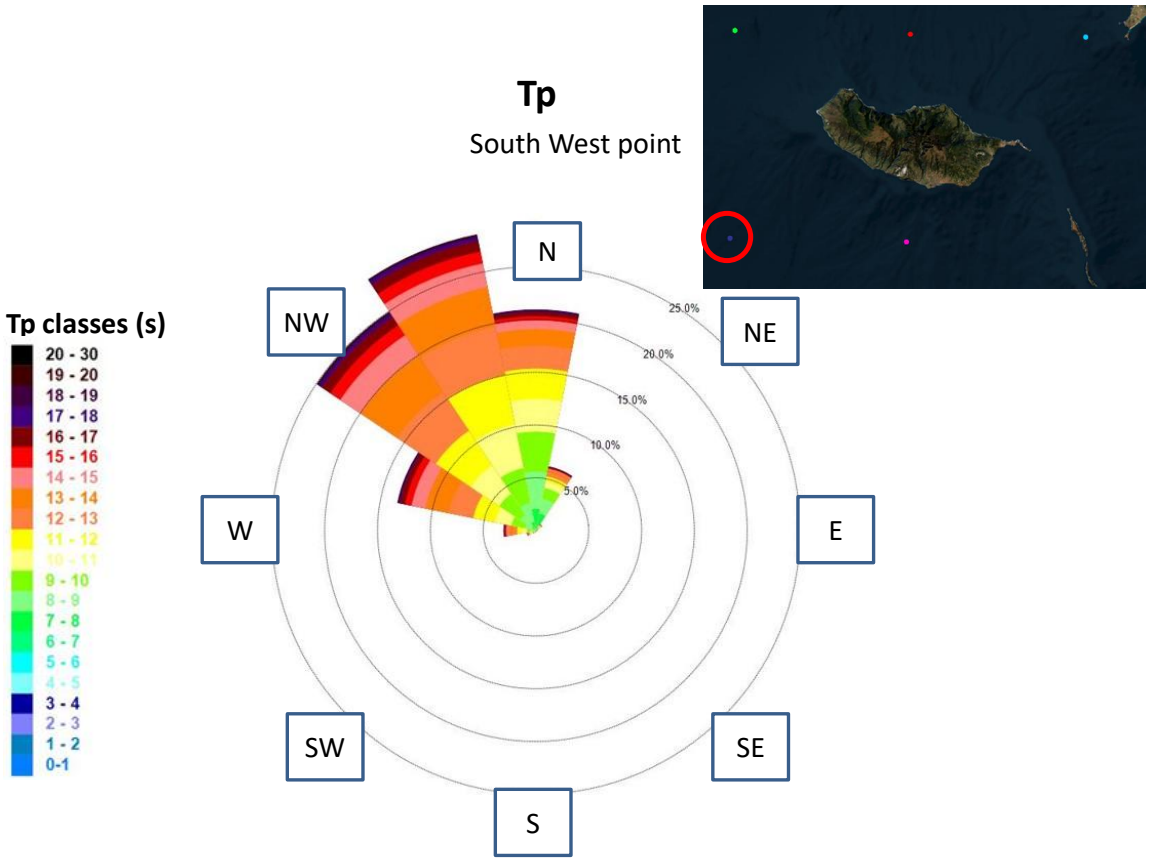


Figure 18, Polar Diagram for Tp, South West point.

Tp classes (s)	Counts
0 – 1	0
1 – 2	0
2 – 3	0
3 – 4	0
4 – 5	95
5 – 6	555
6 – 7	1745
7 – 8	5571
8 – 9	11865
9 – 10	15999
10 - 11	16941
11 - 12	18897

12 - 13	18480
13 - 14	16043
14 - 15	9009
15 - 16	4561
16 - 17	4015
17 - 18	1153
18 - 19	745
19 - 20	298
20 - 30	186

Table 8, wave count in Tp classes, South West point.

Summer versus winter

Figures 19 and 20 display the comparison between the Hs registered in winter and summer, with summer having smaller values as in the other points.

Also, Figure 20 shows that, as for point North West, there are no waves coming from East during summer.

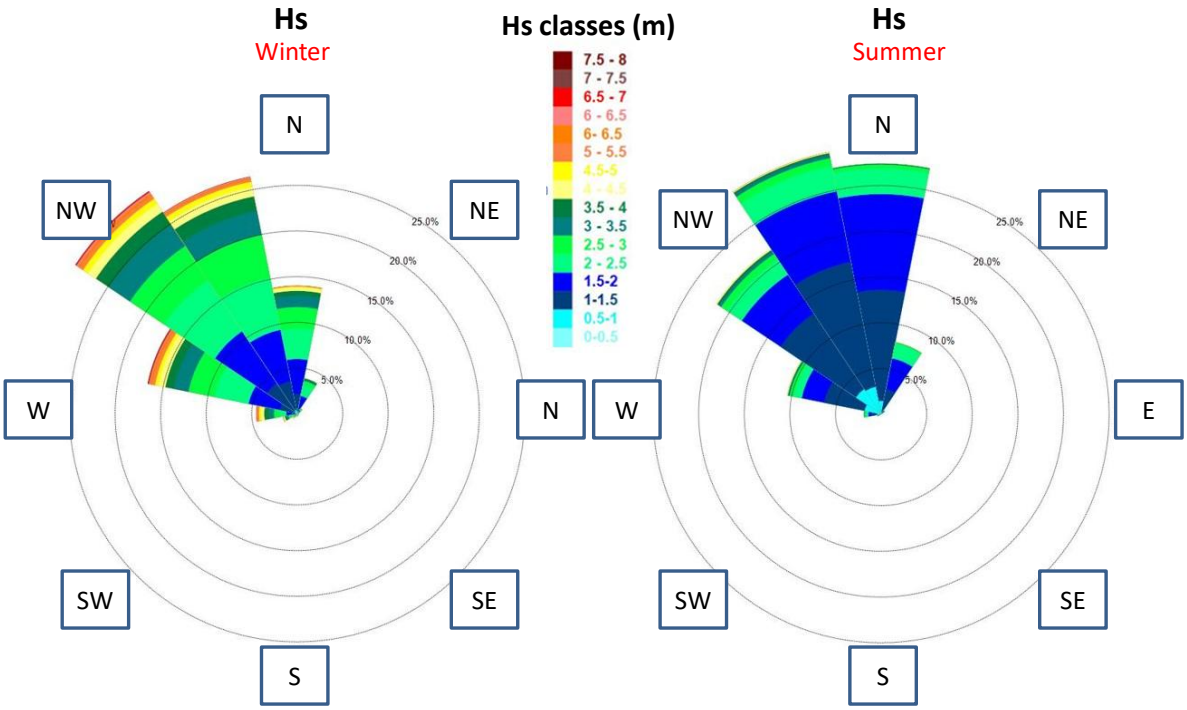


Figure 19, Comparison of Polar Diagram for Hs between Winter and Summer, South West point

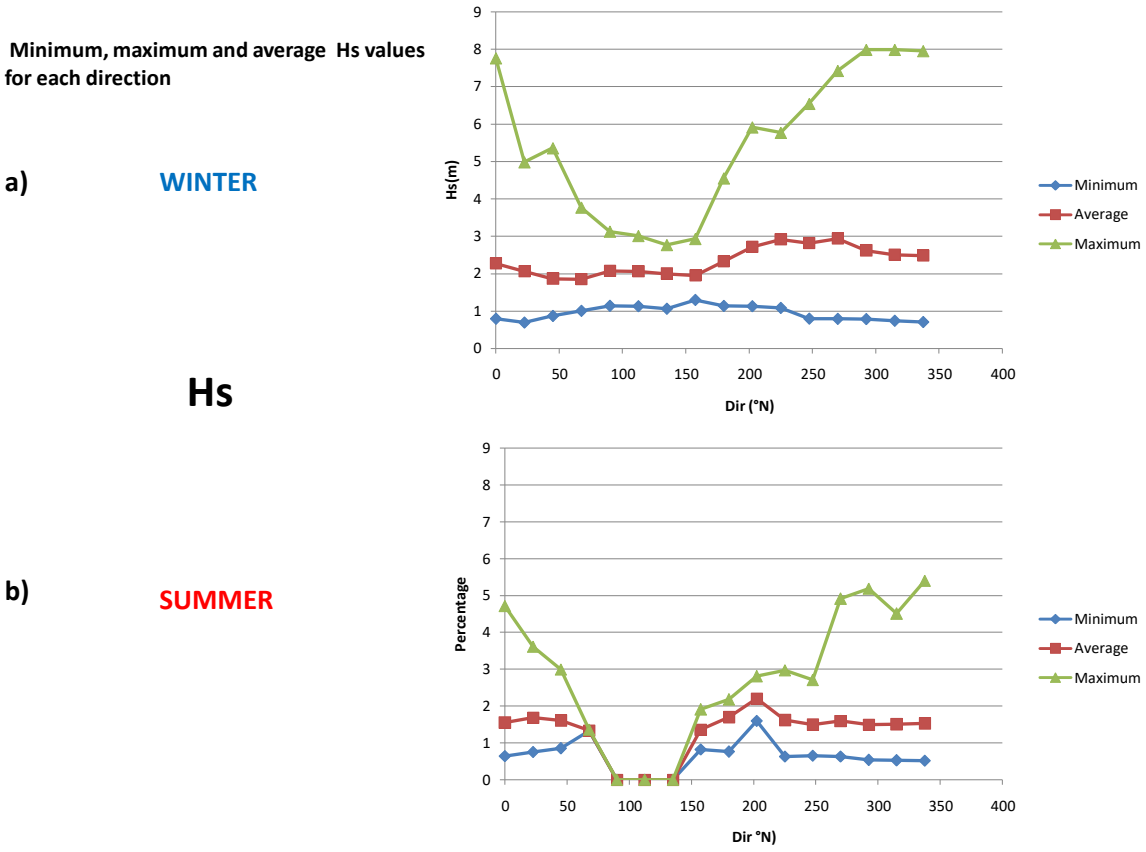


Figure 20, comparison of minimum, maximum, and average Hs values for each direction between: a) Winter; b) Summer. These graphs were generated as output following data processing by WindRosesPro, South West point.