



Assessment of Centurial Extreme Coastal Climate of Bethioua Algeria



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Abstract

Nearshore marine climate at the Port of Bethioua, located on the west of Algeria, were studied using real-time field data and climatological offshore data obtained from the UK Met Office. Total waves, swells in the offshore are hind-casted separately and were validated using buoy measurements were supplied by UKMO at a nominal cost. Shallow water wave transformations are modelled using the Teluray wave-current model to calculate shoaling, depth refraction and current refraction taking bathymetry and tidal flows from the TELEMAC flow model as inputs. The results are of particular importance in the context of planning of port and safe anchorage and movement and anchoring of vessels in the harbour area, in addition, for future developmental programs at the port of Bethioua.

Introduction

Waves are of varied forms, frequencies and directions. To arrive at their climatological picture has always been a challenge to harbour engineers from strategic, economic and commercial points of view. The knowledge of sea state is essential in all operational activities in the marine environment, for the safety of public and for design of coastal and marine engineering structures. Efficacy and life of both floating and fixed marine structures and their cost analysis require good estimates of the extreme sea states [1]. Careful assessment of the wind and wave climates, employing good data and reliable analysis techniques, is necessary for the design of all modern deep and coastal ocean infrastructure systems [2]. Height and period of waves are the most important parameters required in ocean engineering designs [3].

In connection with the future developmental programs at the port of Bethioua, studies were carried out on the offshore wind and wave conditions and nearshore wave transformations in the sea off Bethioua to assess the navigation and berth operability perspectives. This paper presents the results of investigations on the winds and temporal and spatial distribution of waves in the nearshore waters of Bethioua, Algeria for 100 years. Wave activity in the port and its environs is of particular importance in the context of design of port, its operation, ship navigation, safe mooring of vessels and transport of cargo in the harbour area.

Materials and Methods

Algeria is in the Maghreb region of North Africa on the Mediterranean coast. The port of Bethioua is located on the west of Algeria. It has a gas terminal, petrochemical facilities

and a desalination plant. Figure 1 gives the location of the port of Bethioua. Long term Offshore data were obtained from UK Met Office was used for the coastal process and nearshore wave data analysis. UKMO provides Wave data from operational wave forecasting model re-run in a hindcast mode with calibration against measured data from weather ships and satellites. The model results were also validated using the real-time wave rider buoys measurements. Different components of the wave energy spectrum, for example wind-sea and swell, can propagate naturally and separately, each responding realistically to changes in the wind fields. The full wave directional spectrum, which automatically includes both wind-sea and swell, can be re-constituted as required at each time step and at each grid point. Time series data were collected from offshore observation point located at 36.0 °N, 0.46 °W for twenty-year period from March 1987 to Feb 2006. Three-hourly data on wind speed and direction, significant wave height, mean wave period and mean wave direction are analysed. Data on swells generated by remote storms have been analysed separately as long period swell waves are of particular importance in the movement of moored ships. A similar attempt has earlier been successfully carried out around the Korean peninsula [4] and for the northeast Atlantic European coast [5].

The Met Office (UKMO) Global and European Wave Models represent the ocean surface's elevation due to wind stress as an energy spectrum which parameterizes the non-linear interactions in the wave spectrum. The behavior of the individual spectral components (i.e. their growth and dissipation) can be computed. In each 30 minute time step, the wave energy

components move in their respective directions through the grid. The significant wave height (H_s), mean wave period (T_m) and direction (θ m) at each grid point can be integrated out from

a directional spectrum which has 16 direction and 13 frequency components.



Figure 1: Location of the port of Bethioua.

Shallow water transformations of waves consist of refraction, depth induced breaking and shoaling. Shoaling involves changes in wave height due to the waves slowing down as they travel through water of decreasing depth. Refraction involves gradual change in wave direction as waves travel towards the coast, with the wave crests tending to align more nearly parallel with the seabed contours [6]. Added to these are the influences of tidal currents causing changes in wave height. The current effects on waves are likely to be important where peak tidal velocities exceed about 2m/s [7]. In regions where there are strong tidal currents, the influence of tidal currents on waves

(current refraction) is just as important as depth refraction and shoaling. An accurate prediction of the combined effects of depth refraction and current refraction is important in engineering studies in harbours.

Generally, in wave transformation studies selected offshore wave conditions from the probability estimates will be transformed using standard numerical models to study the nearshore wave parameter, which gives biased results. Ultimately, it may cause overestimation/underestimation, hence it increase the error in planning and cost estimation.

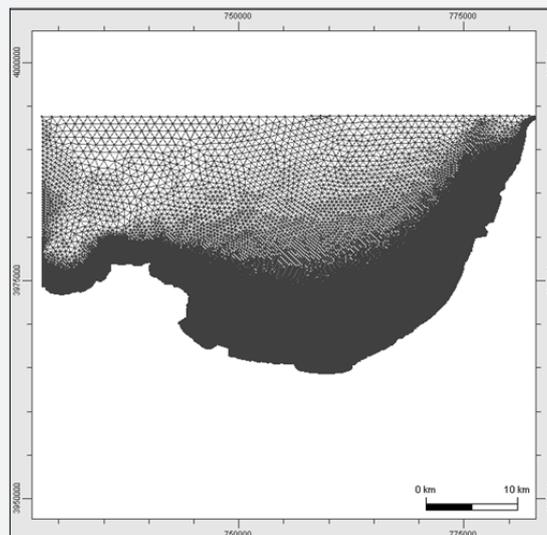


Figure 2 :TELURAY model mesh for Bethioua.

The present study makes use of the Teluray wave-current model to calculate shoaling, depth refraction and current refraction taking bathymetry and tidal flows from the validated TELEMAC2D flow model as inputs. The Teluray model predicts nearshore wave activity by representing the effects of refraction and shoaling on all components of the offshore spectrum using a backtracking ray method. It employs an unstructured finite-element model mesh, which allows the dynamic variation of resolution, so that better resolution can be achieved in areas of particular importance. Figure 2 shows the model mesh for Bethioua.

By this approach, we are transforming each offshore wave ray to the corresponding wave at a nearshore point of interest

with the influence of all corresponding possible natural agents like wind, tidal variation and processes like shoaling, diffraction etc. Sensitivity tests were conducted to test the model sensitivity to different parameters in the numerical model and were calibrated with available in-situ measurements. Result of the study is a nearshore time series to the corresponding offshore time series at a point of interest. The resultant nearshore time series will be further utilised in estimation of wave parameters for next 100 years using a Weibull fit.

Results and Discussion

Spatial and seasonal variations in wind and wave conditions are of particular interest when considering safety and ease of manoeuvring and mooring of vessels in the harbour area.

Offshore winds

Table 1: Annual average wind climate offshore of Bethioua.

U1 To U2		P(U>U1)	Mean Wind Direction (°N)											
			-15	15	45	75	105	135	165	195	225	255	285	315
0	2	0.9871	946	1057	991	973	836	787	747	735	836	879	845	865
2	4	0.88215	2271	3530	3638	2304	1300	1057	1387	2122	2599	2550	1911	1598
4	6	0.61947	1547	4074	4825	1715	512	439	594	1893	4130	3148	1401	980
6	8	0.36688	773	3024	3694	787	182	166	238	692	4253	3053	643	436
8	10	0.18748	245	1452	1866	285	50	54	99	223	3044	2597	274	171
10	12	0.08388	76	488	652	103	7	4	36	43	1693	1898	112	59
12	14	0.03217	22	133	184	47	-	7	7	13	666	937	38	16
14	16	0.01147	5	23	49	11	-	2	9	9	229	402	32	-
16	18	0.00376	7	2	14	5	-	-	-	-	95	122	5	4
18	20	0.00121	-	5	7	-	-	-	-	11	38	36	-	-
20	22	0.00023	-	-	2	-	-	-	-	-	2	13	-	-
22	24	0.00007	-	-	-	-	-	-	-	-	2	4	-	-
24	26	0.00002	-	-	-	-	-	-	-	-	-	2	-	-
Total (parts per thousand)			59	138	159	62	29	25	31	57	176	156	53	41

(Data in parts per hundred thousand; U is the hourly averaged wind speed in m/s; P(U>U1) is the probability of U10 exceeding U1).

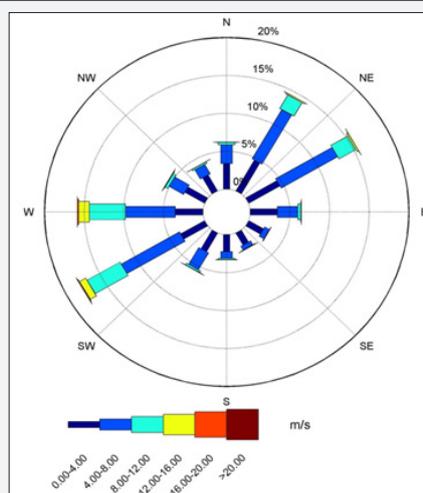


Figure 3 : Annual average wind rose offshore of Bethioua.

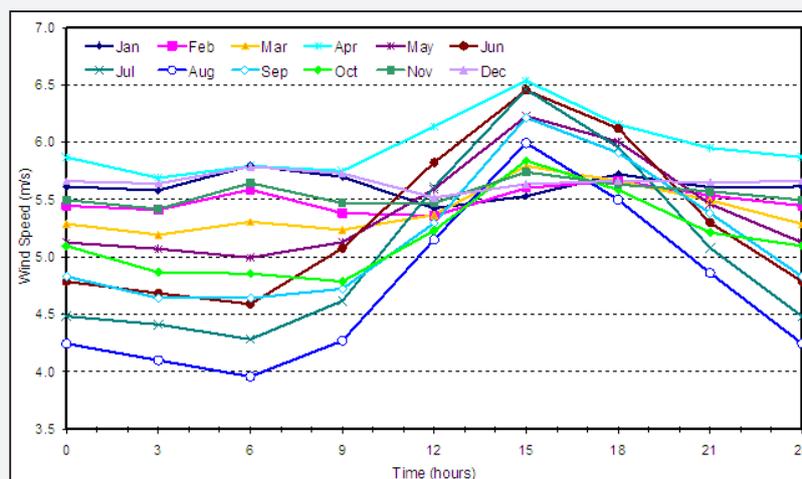


Figure 4 : Diurnal variation of average mean wind speed offshore of Bethioua.

Table 2: Probability of exceedence of wind speeds offshore of Bethioua.

Wind Speed (m/s)	Probability of Occurrence											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0.9883	0.9867	0.9796	0.9932	0.9875	0.9941	0.9953	0.9941	0.9969	0.9854	0.945	0.9985
2	0.8884	0.8813	0.8614	0.8989	0.8843	0.9108	0.8894	0.868	0.8925	0.8635	0.852	0.896
4	0.6195	0.6034	0.6087	0.6579	0.645	0.6461	0.6191	0.5773	0.6265	0.5885	0.6026	0.6396
6	0.3818	0.3552	0.3663	0.4355	0.3807	0.3704	0.3517	0.3031	0.3518	0.3506	0.3636	0.3926
8	0.2116	0.1979	0.198	0.2561	0.1931	0.1737	0.1509	0.1063	0.1638	0.1795	0.1996	0.2216
10	0.0989	0.1003	0.0936	0.1432	0.079	0.0634	0.0458	0.0253	0.0656	0.0779	0.1029	0.1135
12	0.0418	0.0459	0.0401	0.0638	0.0263	0.0167	0.0098	0.0053	0.0145	0.0267	0.0441	0.0526
14	0.0174	0.0191	0.014	0.0254	0.0064	0.0029	0.0009	0.0004	0.0022	0.0081	0.0184	0.0233
16	0.0055	0.0075	0.0047	0.0101	0.0019	-	-	-	-	0.0015	0.007	0.0074
18	0.0021	0.004	0.0011	0.0029	0.0002	-	-	-	-	0.0004	0.0013	0.0028
20	0.0006	0.0012	-	0.0002	-	-	-	-	-	-	0.0002	0.0006
22	-	0.0005	-	-	-	-	-	-	-	-	-	0.0004
24	-	-	-	-	-	-	-	-	-	-	-	0.0002

(Total number of hours in period = 166560).

Wind conditions offshore of Bethioua are presented in Figure 3 as a rose diagram. The area is mostly influenced by westerly and northeasterly winds. Winds blowing from the sector centred at 270 °N are the strongest having speeds in the range 24–26m/s. The most frequently occurring winds are from 240 °N, which account for 18% of records. Table 1 gives the annual average wind climate offshore of Bethioua. Table 2 presents the average monthly probability of exceedence of wind speeds offshore of Bethioua for all the months based on wind data for March 1987 - February 2006. The wind climate of the region consists of two seasons. The winds are strongest during winter months (October-April) and relatively calm during summer months (June-September). Figure 4 presents the diurnal variation of average mean wind speed for all months at the observation point located at 36.0 °N, 0.46 °W. The wind speed shows higher variations during summer with average mean speed reaching

a maximum in the afternoon (15:00 GMT) with slower wind in the early morning (06:00 GMT). The greatest variation in mean speed is seen in August with mean speeds ranging between 4.0m/s and 6.0m/s. Diurnal variations are much lower in mean offshore wind speed during winter months.

Offshore waves

The offshore wave climate is presented in Tables 3-5 as scatter tables of significant wave height (Hs) in metres against mean wave direction, significant wave height against mean wave period (Tm) and significant wave height against hourly averaged mean wind speed (U) in m/s respectively. The data, in parts per hundred thousand, are based on 166560 hours of UKMO predictions for March 1987 - February 2006. Table 3 shows that the wave climate is dominated by waves from the 30 °N sector, which accounts for 39% of wave conditions and

waves from the 270 °N sector which accounts for a further 24%. This is consistent with the geometry of the offshore wave generating area in this region. The largest waves occur in the 30

°N sector with waves having Hs 6.5 to 7.0m. The average annual distribution of significant wave heights for total sea offshore of Bethioua is illustrated in the rose diagram presented in Figure 5.

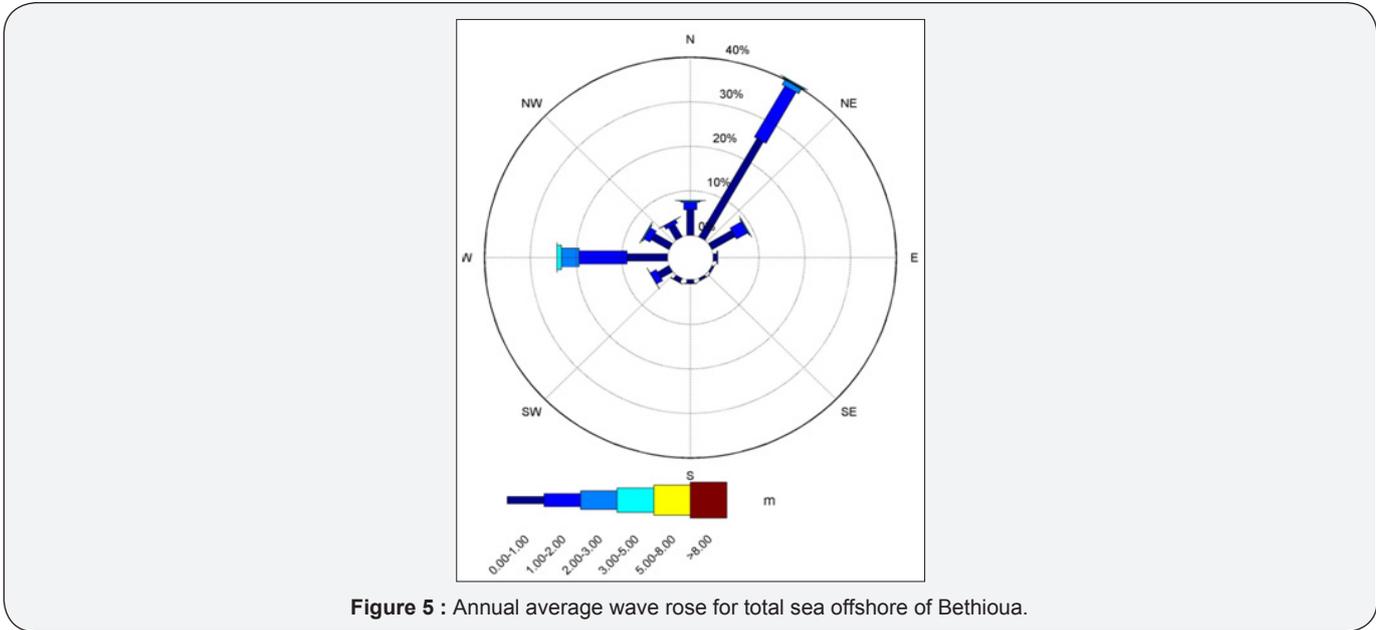


Figure 5 : Annual average wave rose for total sea offshore of Bethioua.

Table 3: Annual average wave climate offshore of Bethioua (significant wave height (m) against direction).

H1 to H2 (m)		P(H>H1)	Mean Wave Direction (°N)											
			-15	15	45	75	105	135	165	195	225	255	285	315
0	0.5	0.98646	1999	5292	2345	380	157	137	187	312	627	1819	1481	1354
0.5	1	0.82556	3309	19521	4069	402	303	373	580	683	2197	6920	2795	1906
1	1.5	0.39499	1113	9564	2341	137	34	14	45	106	1293	6191	967	558
1.5	2	0.17134	457	3235	773	9	-	5	-	4	191	4153	459	227
2	2.5	0.07621	177	1110	225	-	-	-	-	-	29	2426	216	54
2.5	3	0.03384	79	317	72	-	-	-	-	-	23	1344	79	34
3	3.5	0.01436	50	128	25	-	-	-	-	-	5	643	36	7
3.5	4	0.0054	16	61	5	-	-	-	-	-	2	240	18	-
4	4.5	0.00198	4	43	2	-	-	-	-	-	-	77	-	-
4.5	5	0.00072	2	5	4	-	-	-	-	-	-	18	-	-
5	5.5	0.00043	4	5	2	-	-	-	-	-	-	7	-	-
5.5	6	0.00025	5	5	-	-	-	-	-	-	-	4	-	-
6	6.5	0.00011	2	5	-	-	-	-	-	-	-	-	-	-
6.5	7	0.00004	-	4	-	-	-	-	-	-	-	-	-	-
Total (parts per thousand)	72	393	99	9	5	5	8	11	44	238	61	41		

(P(H>H1) is the probability of Hs exceeding H1).

Table 4: Annual average wave climate offshore of Bethioua (significant wave height against mean wave period).

H1 to H2		P(H>H1)	Mean Wave Period in seconds (Tm)															
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0.5	0.98646	-	-	-	13370	2399	285	34	2	-	-	-	-	-	-	-	-
0.5	1	0.82556	-	-	-	22487	17052	2934	519	58	4	2	-	2	-	-	-	-
1	1.5	0.39499	-	-	-	1821	16104	3114	1106	193	23	4	-	-	-	-	-	-
1.5	2	0.17134	-	-	-	68	3091	5602	497	236	20	-	-	-	-	-	-	-
2	2.5	0.07621	-	-	-	-	56	3701	420	49	11	-	-	-	-	-	-	-
2.5	3	0.03384	-	-	-	-	-	391	1535	18	5	-	-	-	-	-	-	-
3	3.5	0.01436	-	-	-	-	-	5	836	49	5	-	-	-	-	-	-	-
3.5	4	0.0054	-	-	-	-	-	-	81	259	2	-	-	-	-	-	-	-
4	4.5	0.00198	-	-	-	-	-	-	7	115	2	2	-	-	-	-	-	-
4.5	5	0.00072	-	-	-	-	-	-	-	14	14	-	-	-	-	-	-	-
5	5.5	0.00043	-	-	-	-	-	-	-	4	14	-	-	-	-	-	-	-
5.5	6	0.00025	-	-	-	-	-	-	-	-	14	-	-	-	-	-	-	-
6	6.5	0.00011	-	-	-	-	-	-	-	-	4	4	-	-	-	-	-	-
6.5	7	0.00004	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-
Total (parts per thousand)			0	0	0	377	387	160	50	10	1	0	0	0	0	0	0	0

(P(H>H1) is the probability of Hs exceeding H1).

Table 5: Concurrence of waves with wind offshore of Bethioua (significant wave height against wind speed).

H1 To H2		P(H>H1)	Mean Wind Speed (m/s)													
			0	2	4	6	8	10	12	14	16	18	20	22	24	26
			2	4	6	8	10	12	14	16	18	20	22	24	26	28
0	0.5	0.98646	3826	8006	3808	427	22	2	-	-	-	-	-	-	-	-
0.5	1	0.82556	5274	14130	14474	7671	1392	106	9	-	-	-	-	-	-	-
1	1.5	0.39499	1084	3237	5485	7365	4380	742	61	11	-	-	-	-	-	-
1.5	2	0.17134	240	726	1189	1933	3165	1888	326	49	-	-	-	-	-	-
2	2.5	0.07621	31	126	234	436	1091	1616	589	90	20	4	-	-	-	-
2.5	3	0.03384	5	18	50	81	220	639	675	213	34	13	-	-	-	-
3	3.5	0.01436	-	4	11	23	67	139	315	245	72	14	4	2	-	-
3.5	4	0.0054	-	-	-	2	18	32	65	124	68	32	-	-	-	-
4	4.5	0.00198	-	-	2	-	5	5	22	34	40	13	5	-	-	-
4.5	5	0.00072	-	-	-	2	-	-	4	4	7	7	4	2	-	-
5	5.5	0.00043	-	-	-	-	-	2	2	-	4	7	-	2	2	-
5.5	6	0.00025	-	-	-	-	-	-	2	2	5	4	2	-	-	-
6	6.5	0.00011	-	-	-	-	-	-	-	-	5	-	2	-	-	-
6.5	7	0.00004	-	-	-	-	-	-	-	-	-	4	-	-	-	-
Total (Parts per thousand)			105	262	253	179	104	52	21	8	3	1	0	0	0	0

(P(H>H1) is the probability of Hs exceeding H1)

Table 4 indicates that the waves have mean periods mostly in the range of 3 to 7 seconds, although mean periods in the range 7 to 12 seconds are also noted on isolated occasions. The largest waves in the data set have mean periods in the range 8 to 10 seconds. Table 5 shows the concurrence of waves with wind offshore of Bethioiua. As expected, there is a general trend towards larger waves when wind speeds are high. However, there are few occurrences of high waves without high wind speeds suggesting that sea conditions dominated by large swell components are rare. Wave conditions above 4.5m are generally accompanied by winds of 12m/s or greater. Such winds can also be accompanied by significantly lower waves.

Offshore wave scatter tables

Offshore two-way scatter plots of significant wave height against direction and significant wave height against wave period are given in Tables 6 & 7 respectively. In 41% of the records, the wave climate is heavily dominated by swells from the 30 °N direction sector. This direction sector also produces the largest swells with significant wave heights reaching 4.5 to 5.0m. Figure 6 presents a clear picture of the annual average wave rose for swells offshore of Bethioua. Wind wave periods are in the range of 2 to 10s. The largest swells fall in the range of 10 to 14s. There are also some very long period swells in the range $T_m = 14$ to 26s, although these have relatively low wave heights ($H_s < 1m$).

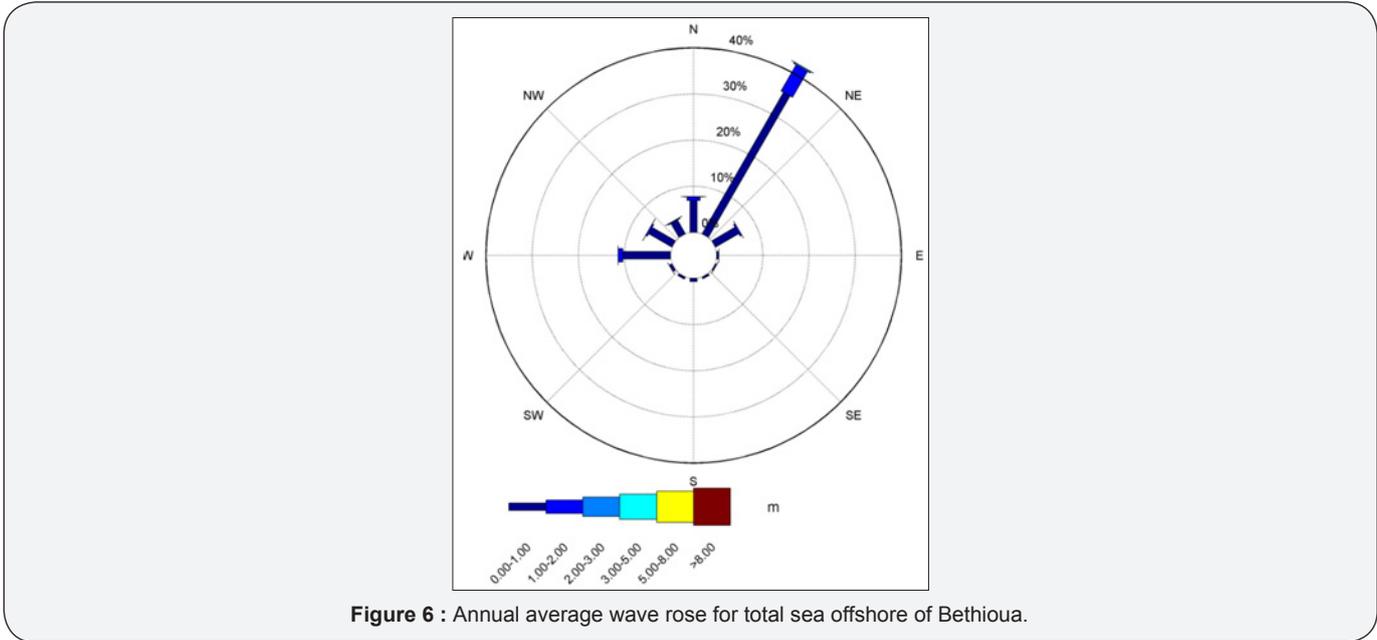


Figure 6 : Annual average wave rose for total sea offshore of Bethioua.

Table 6: Annual average swell climate offshore of Bethioua (significant wave height $H_s(m)$ against direction).

H1 To H2	P(H>H1)	Mean Wave Direction (°N)												
		-15	15	45	75	105	135	165	195	225	255	285	315	
0	0.5	0.79335	4040	17095	4728	207	99	63	74	117	441	5729	3682	2385
0.5	1	0.40675	2305	17426	1816	213	218	366	587	376	186	4424	1920	1106
1	1.5	0.09733	591	5065	393	32	4	-	-	-	5	893	339	202
1.5	2	0.0221	131	1376	40	-	-	-	-	-	-	133	47	31
2	2.5	0.00452	32	294	4	-	-	-	-	-	-	14	11	4
2.5	3	0.00094	9	56	2	-	-	-	-	-	-	2	-	-
3	3.5	0.00025	2	13	-	-	-	-	-	-	-	-	2	-
3.5	4	0.00009	-	4	-	-	-	-	-	-	-	-	-	-
4	4.5	0.00005	-	4	-	-	-	-	-	-	-	-	-	-
4.5	5	0.00002	-	2	-	-	-	-	-	-	-	-	-	-
Total (parts per thousand)			71	413	70	5	3	4	7	5	6	112	60	37

Based on UKMO predictions for March 1987 - February 2006; P(H>H1) is the probability of H_s exceeding H_1 .

Table 7: Annual average swell climate offshore of Bethioua (significant wave height Hs against mean wave period).

H1 To H2	P(H>H1)	Mean Wave Period in Seconds (Tm)															
		0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	
0	0.5	0.79335	-	3963	22853	8129	2828	735	92	22	2	2	2	5	29	0	0
0.5	1	0.40675	-	2669	17700	7822	2138	539	54	5	-	-	2	2	11	0	0
1	1.5	0.09733	-	175	2547	3622	964	191	25	-	-	-	-	-	-	0	0
1.5	2	0.0221	-	-	270	1034	376	67	11	-	-	-	-	-	-	0	0
2	2.5	0.00452	-	-	23	196	108	27	4	-	-	-	-	-	-	0	0
2.5	3	0.00094	-	-	-	29	25	11	4	-	-	-	-	-	-	0	0
3	3.5	0.00025	-	-	-	-	7	7	2	-	-	-	-	-	-	0	0
3.5	4	0.00009	-	-	-	-	-	2	2	-	-	-	-	-	-	0	0
4	4.5	0.00005	-	-	-	-	-	2	2	-	-	-	-	-	-	0	0
4.5	5	0.00002	-	-	-	-	-	2	-	-	-	-	-	-	-	0	0
Total (parts per thousand)			0	68	434	208	64	16	2	0	0	0	0	0	0	0	0

Based on UKMO predictions for March 1987 – February 2006; P(H>H1) is the probability of Hs exceeding H1.

Extreme offshore conditions

Extreme wind and wave conditions offshore of Bethioua are obtained by fitting probability distributions to the data. It is well accepted that the three-parameter Weibull distribution generally fits this type of data. Extreme conditions have been derived by fitting Weibull distributions to the sectors of interest

for return periods of 1, 5, 10, 50 and 100 years. Table 8 presents the estimated extreme wind speeds offshore of Bethioua. The most severe winds are predicted in the sector centred at 270 °N. Estimated wind speed of return period one year is 19.2m/s and 25.1m/s is the corresponding wind speed for the return period of 100 years.

Table 8: Extreme wind speeds (m/s) offshore of Bethioua.

Return Period	Wind Direction (°N)													
	0	30	60	90	120	150	180	210	240	270	300	330	0-360	
1	12.4	14.5	15.6	12.8	8.5	9.2	10.9	13	17.8	19.2	13.4	11.4	19.7	
5	15	16.5	17.8	15.4	10.3	11.8	14.1	16.1	19.9	21.5	16.3	13.9	22	
10	16	17.3	18.7	16.5	11.1	12.9	15.5	17.3	20.8	22.4	17.5	15	22.9	
50	18.4	19.1	20.8	18.8	12.7	15.4	18.6	20.2	22.6	24.3	20.1	17.3	25	
100	19.4	19.9	21.6	19.8	13.4	16.4	19.9	21.5	23.4	25.1	21.3	18.2	25.8	

Table 9: Extreme wave conditions offshore of Bethioua (total sea).

Return Period(years)	Wave Direction (°N)											
	270		300		330		360		30		60	
	Hs	Tm	Hs	Tm	Hs	Tm	Hs	Tm	Hs	Tm	Hs	Tm
1	2.4	5.8	4.5	8	3.3	6.8	2.5	5.9	3.7	7.3	4.6	8.1
5	2.9	6.5	5.2	8.6	4.2	7.7	3.2	6.7	5	8.5	5.6	9
10	3.2	6.7	5.4	8.8	4.6	8.1	3.5	7	5.6	9	6.1	9.3
50	3.7	7.3	6	9.2	5.5	8.8	4.2	7.7	7.1	10	7.2	10.1
100	3.9	7.5	6.2	9.4	5.9	9.1	4.5	8	7.7	10.5	7.7	10.5

Total extreme offshore sea waves at Bethioua are presented in Table 9. Most severe waves approach from the sector centred at 60 °N. The 1-year return period for this direction is predicted to be Hs = 4.6m, increasing to 7.7m for the 100-year event. For the higher return periods, similar wave heights are indicated from

the 30 °N sector. Extreme swell conditions offshore of Bethioua are presented in Table 10. The most severe swell components occur in the 30 °N sector, giving a 1 in 1-year component of Hs = 3.0m, rising to a 1 in 100-year swell component of Hs = 4.9m.

Table 10: Extreme wave conditions offshore of Bethioua (swells).

Return Period in Years	Wave Direction (°N)											
	270		300		330		360		30		60	
	Hs	Tm	Hs	Tm	Hs	Tm	Hs	Tm	Hs	Tm	Hs	Tm
1	1.8	7.7	1.7	7.4	1.5	6.9	2.1	8.1	3	9.8	1.6	7.2
5	2.2	8.4	2.3	8.5	1.9	7.7	2.6	9.1	3.7	10.9	2	8.1
10	2.4	8.7	2.5	9	2	8	2.8	9.5	4	11.3	2.2	8.4
50	2.7	9.3	3.1	9.9	2.4	8.7	3.4	10.4	4.6	12.2	2.6	9.2
100	2.8	9.5	3.3	10.3	2.5	9	3.6	10.7	4.9	12.6	2.8	9.5

Shallow water wave transformations

As waves propagate from deep water into the shallow water, all the wave parameters, except wave period get modified by shallow water processes including refraction, and shoaling [8]. The sheltering effect of the surrounding coastline may also be important in determining nearshore wave climate. The Teluray wave transformation model provides an effective and convenient tool to model these processes. This model predicts wave activity at nearshore sites by representing the effects of refraction and shoaling on all components of a given offshore wave spectrum by using an efficient backtracking ray method. This method involves the tracking of wave rays from the nearshore point to the offshore boundary of a grid system covering the area of study. Since the ray paths are reversible, each ray gives information on the energy propagation towards the shore. This method is used to transform long-term offshore wave time series data to nearshore time series in presence of tidal variation and natural wave transformations as it travels

from offshore to nearshore.

Figure 7 shows the model bathymetry for Bethioua extracted from a digitised global bathymetry database based on latest navigation charts. The Teluray model uses dynamically varying unstructured finite-element model mesh that provides greater resolution in areas of particular importance. Figure 8 shows the model mesh for Bethioua. The co-ordinate system for the model is UTM Zone 30N (WGS84). The nearshore refraction point for Bethioua was located at 749723mE, 3967867mN in a depth of -30mCD. The wave transformation simulations for Bethioua are carried out using a still water level of +0.5mCD, approximately equal to the local mean sea level with corresponding tidal current. The JONSWAP spectrum was assumed for the offshore wave conditions. This is a reasonable assumption for an enclosed sea area such as the western Mediterranean where local winds are dominant. Peak period for the standard JONSWAP spectrum is given by 1.28 times Tm.

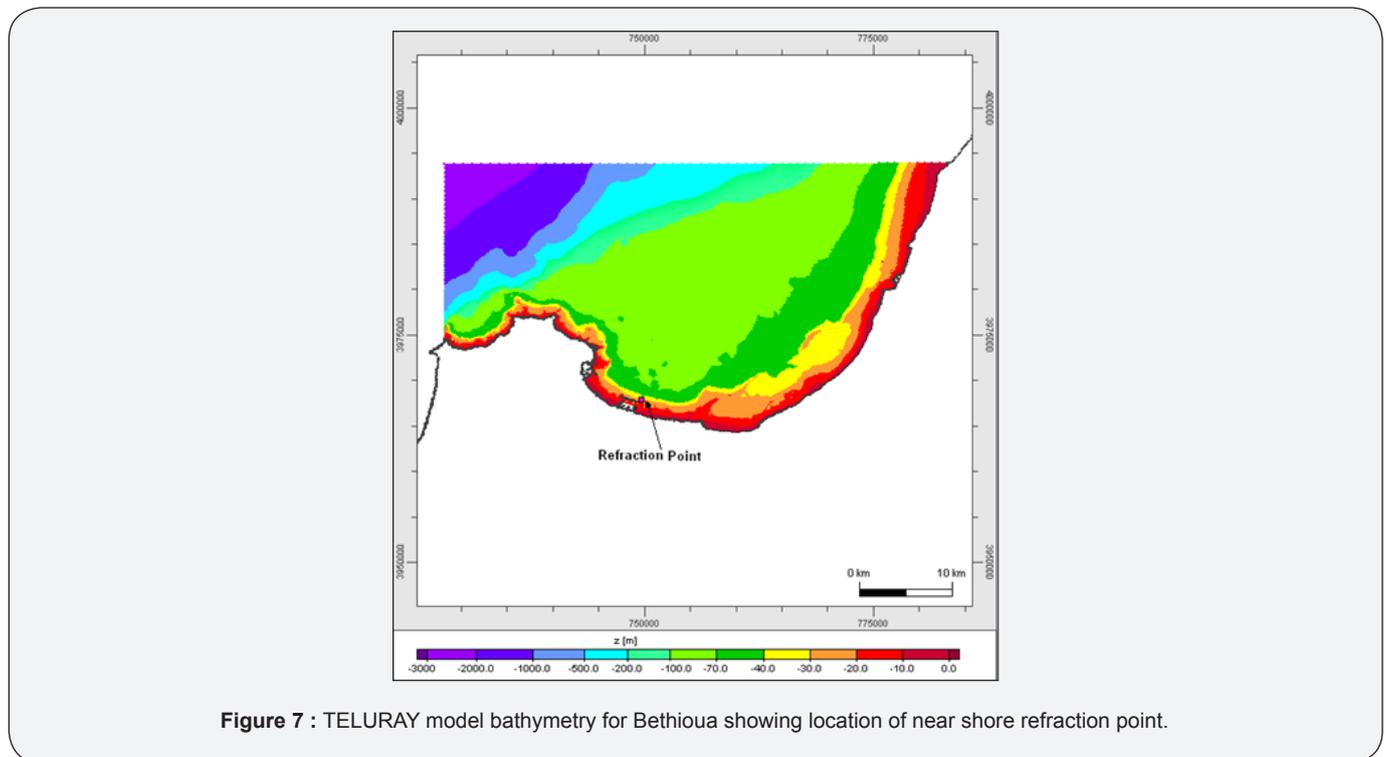


Figure 7 : TELURAY model bathymetry for Bethioua showing location of near shore refraction point.

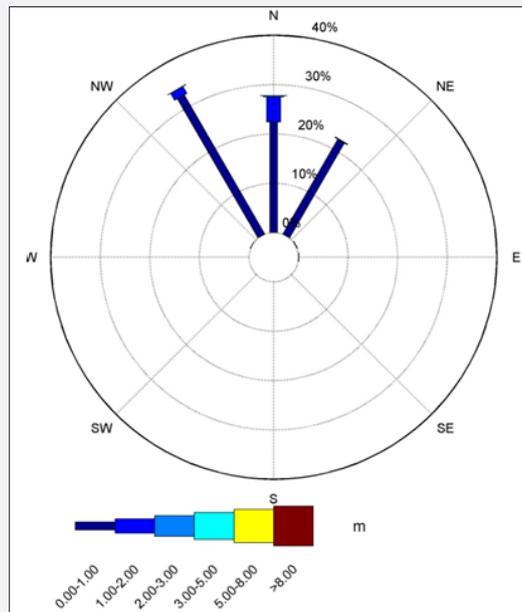


Figure 8 : TELURAY model bathymetry for Bethioua showing location of near shore refraction point.

The total wave climate nearshore at Bethioua is dominated by waves from directions between 10°N and 30°N (Figure 9). These waves account for about 50% of the wave records. There is a secondary peak from around 330°N. The largest wave approach

is from directions between 10°N and 20°N, having Hs between 5.0 and 5.5m predicted in the 20-year data set. Nearshore peak periods are typically around 1.38 times Tm.

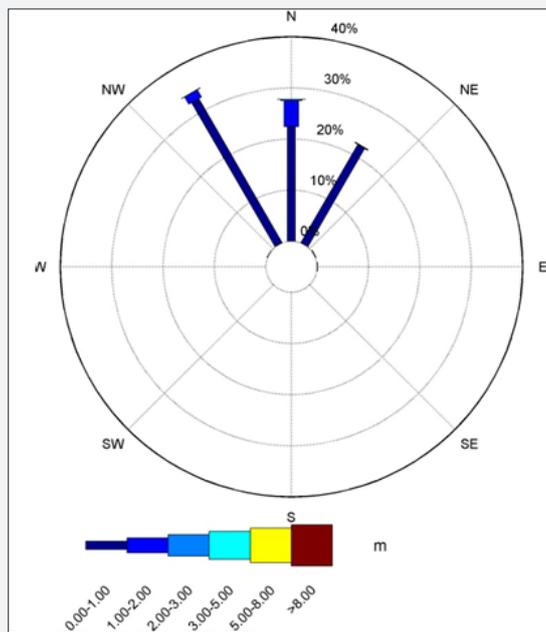


Figure 9 : Nearshore annual wave rose for swell off Bethioua.

The swell wave component nearshore at Bethioua is presented in Figure 9 as a wave rose plot. Again, the climate is dominated by waves arriving from 10°N – 30°N which account for about 45% of nearshore wave records. The largest swell components also approach the Port of Bethioua from 10°N – 20°N, reaching the range Hs = 3.5 to 4.0m in the 20-year data set. To validate the teleuray results we have considered extremes.

Calculated offshore extremes are modelled with help of wave propagation model SWAN. SWAN results are then compared with nearshore extremes from the teluray model.

To compare the validity of nearshore extremes estimated after transforming the entire. In addition to transforming the time series wave data, the Teluray model is used to transform

the extreme wave conditions to nearshore. For each offshore direction sector, the predicted extreme wave condition is applied with directions corresponding to the centre of the sector and 10 degrees on either side. The largest resulting nearshore extreme waves for each sector are then selected. The near shore extreme wave conditions are presented in Table 11 for total sea conditions. The most severe near shore waves are those arriving from the sector centred at 30 °N. For this sector, a 1-year return period wave height $H_s = 3.0\text{m}$ is predicted with a near shore

direction of 13 °N, increasing to $H_s = 5.9\text{m}$ with near shore direction of 15 °N for a return period of 100 years. Nearshore extreme swell component predictions are presented in Table 12. As expected, the largest extreme swell components are caused by offshore waves from the directions centred at 30 °N. For this sector, a 1-year return period swell height $H_s = 2.5\text{m}$ is predicted with nearshore direction of 17 °N, increasing to $H_s = 4.2\text{m}$ with a direction of 16 °N for a return period of 100 years.

Table 11: Nearshore extreme wave conditions at Bethioua (total sea).

Offshore Sector (°N)	Return Period (years)	Offshore			Nearshore		
		Hs	Tm	Dir	Hs	Tm	Dir
		(m)	(s)	(°N)	(m)	(s)	(°N)
270	1	2.4	5.8	280	0.8	5.7	336
	5	2.9	6.5	280	0.9	6	337
	10	3.2	6.7	280	1	6.3	338
	50	3.7	7.3	280	1.1	6.8	340
	100	3.9	7.5	280	1.2	6.9	340
300	1	4.5	8	310	2.4	7.4	351
	5	5.2	8.6	310	2.7	7.8	352
	10	5.4	8.8	310	2.7	8	353
	50	6	9.2	310	3	8.4	354
	100	6.2	9.4	310	3.1	8.5	354
330	1	3.3	6.8	340	2.6	6.5	359
	5	4.2	7.7	340	3.1	7.2	0
	10	4.6	8.1	340	3.4	7.6	1
	50	5.5	8.8	340	3.9	8.1	2
	100	5.9	9.1	340	4.2	8.4	3
360	1	2.5	5.9	10	2.3	5.9	8
	5	3.2	6.7	10	2.7	6.4	9
	10	3.5	7	10	3	6.8	9
	50	4.2	7.7	10	3.4	7.3	10
	100	4.5	8	10	3.6	7.6	10
30	1	3.7	7.3	20	3	7	13
	5	5	8.5	20	3.9	8.1	14
	10	5.6	9	20	4.3	8.5	14
	50	7.1	10	20	5.4	9.5	14
	100	7.7	10.5	20	5.9	10	15
60	1	4.6	8.1	50	3	7.8	22
	5	5.6	9	50	3.6	8.6	22
	10	6.1	9.3	50	3.9	9	22
	50	7.2	10.1	50	4.6	9.8	22
	100	7.7	10.5	50	5	10.2	22

Table 12: Nearshore extreme wave conditions at Bethioua (swell).

Offshore Sector (°N)	Return Period (years)	Offshore			Nearshore		
		Hs	Tm	Dir	Hs	Tm	Dir
		(m)	(s)	(°N)	(m)	(s)	(°N)
270	1	1.8	7.7	280	0.3	7.4	336
	5	2.2	8.4	280	0.4	8	338
	10	2.4	8.7	280	0.4	8.2	339
	50	2.7	9.3	280	0.4	8.6	340
	100	2.8	9.5	280	0.4	8.7	341
300	1	1.7	7.4	310	0.8	6.8	341
	5	2.3	8.5	310	1	7.6	344
	10	2.5	9	310	1.1	7.9	345
	50	3.1	9.9	310	1.3	8.6	348
	100	3.3	10.3	310	1.4	9	349
330	1	1.5	6.9	340	1.2	6.6	352
	5	1.9	7.7	340	1.5	7.1	354
	10	2	8	340	1.5	7.4	354
	50	2.4	8.7	340	1.8	8	356
	100	2.5	9	340	1.8	8.2	356
360	1	2.1	8.1	10	1.9	7.8	11
	5	2.6	9.1	10	2.3	8.6	12
	10	2.8	9.5	10	2.4	9	12
	50	3.4	10.4	10	2.9	9.9	12
	100	3.6	10.7	10	3.1	10.2	12
30	1	3	9.8	20	2.5	9.3	17
	5	3.7	10.9	20	3.1	10.4	17
	10	4	11.3	20	3.4	10.8	16
	50	4.6	12.2	20	3.9	11.8	16
	100	4.9	12.6	20	4.2	12.2	16
60	1	1.6	7.2	50	1.1	7	31
	5	2	8.1	50	1.3	7.8	30
	10	2.2	8.4	50	1.4	8.1	30
	50	2.6	9.2	50	1.7	8.9	29
	100	2.8	9.5	50	1.8	9.2	29

Conclusion

Transformation all offshore time series wave data to nearshore point of interest gave more realistic and reasonable results compared to the conventional practice of transforming selected wave rays to nearshore for estimating long-term extremes. The method adopted considered all time-dependant metocean parameters to transform offshore time series waves to nearshore time series. Offshore wind and wave data obtained from the UK Met Office are analysed for a point at 36.0 °N, 0.46 °W. The offshore wind climate is dominated by westerly and northeasterly winds. The strongest winds come from the sector centred at 270 °N, with maximum speeds in the range 24–26m/s.

The waves offshore at Bethioua are dominated by waves from the sectors centred at 30 °N and 270 °N. The largest waves occur in the 30 °N sector with waves predicted up to Hs=6.5 to 7.0m. The waves have mean periods in the range of 3-7 seconds. Mean periods in the range 7 to 12 seconds are also observed on isolated occasions. In the nearshore at Bethioua, the largest extreme wave heights are predicted in the sector centred at 60 °N. The 1-year return period condition for this direction is found to be Hs = 4.6m, increasing to 7.7m for the 100-year event.

The most severe nearshore waves are caused by offshore waves arriving from ~ 30 °N. These waves have a 1-year return period wave height Hs = 3.0m with a nearshore direction of 13

°N, increasing to $H_s = 5.9\text{m}$ with near shore direction of 15°N for a return period of 100 years.

To update

- I. Graphs with Teluray and direct Teluray exceedance
- II. Downtime estimate with two methods
- III. Sensitivity and validation tests
- IV. About the friction terms
- V. Telemac-teluray coupling
- VI. Update the write-up with graphs
- VII. Literature

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