

OWC-Harbour Project

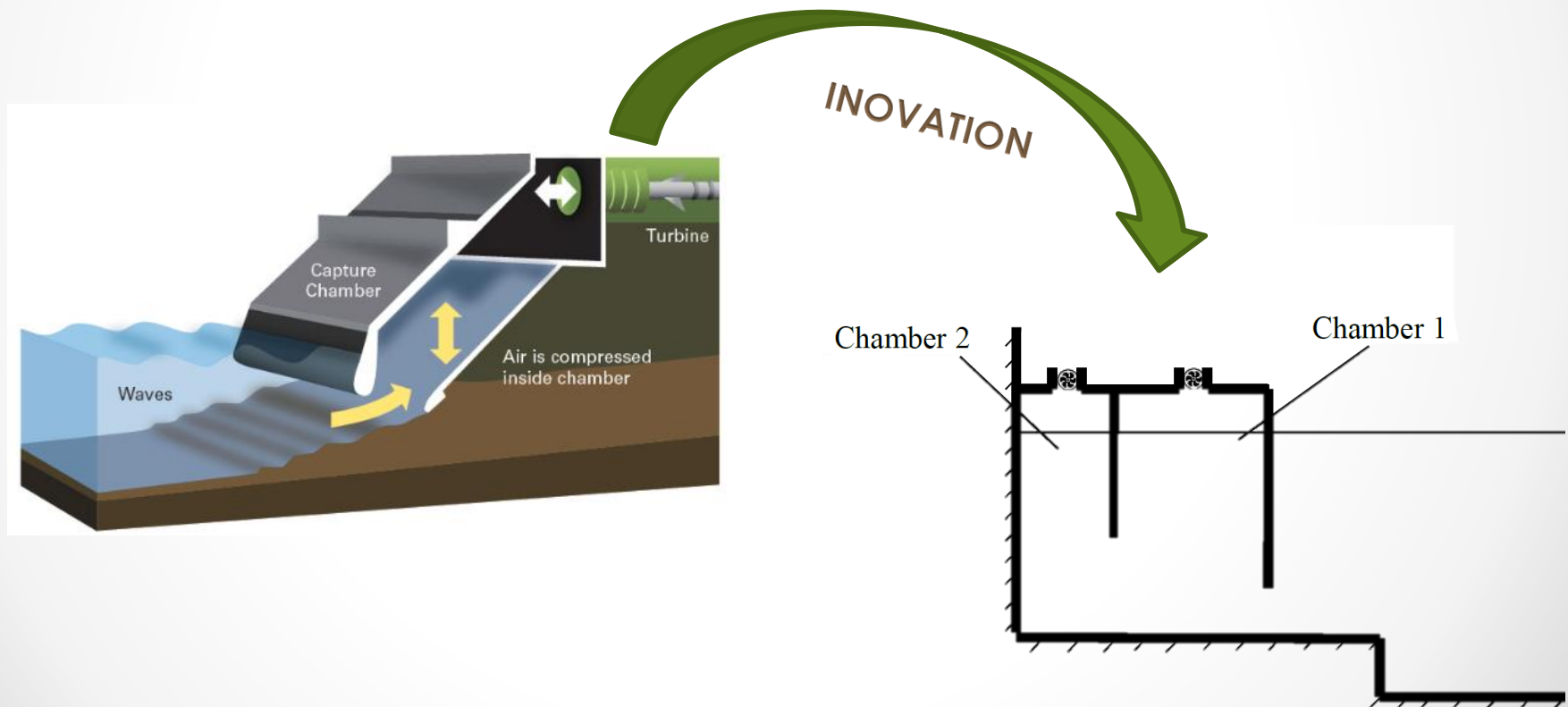
Sea State and Energy Assessment

SUMMARY

- I. OWC Concept
- II. Wave Climate Assessment
- III. Wave Energy Assessment
- IV. Conclusion

OWC - CONCEPT

- Oscillating Water Column



OWC - CONCEPT

- PROS :
 - ✓ Moving parts outside of the water
 - ✓ Easy access for maintenance
 - ✓ Easy connection to power grid
 - ✓ Initial building cost
- CONS :
 - ❖ Non-axisymmetric
 - ❖ Suffer severe damages in case of strong storm events
 - ❖ Eye sore
 - ❖ Noisy

Work Resume

Objective : Find the best installation site

Target sites :

- a. Pico Island (Azores) : Madalena & São Roque
- b. Sines (Mainland Portugal) : West & East docks
- c. Madeira : Seixal & São Paul do Mar

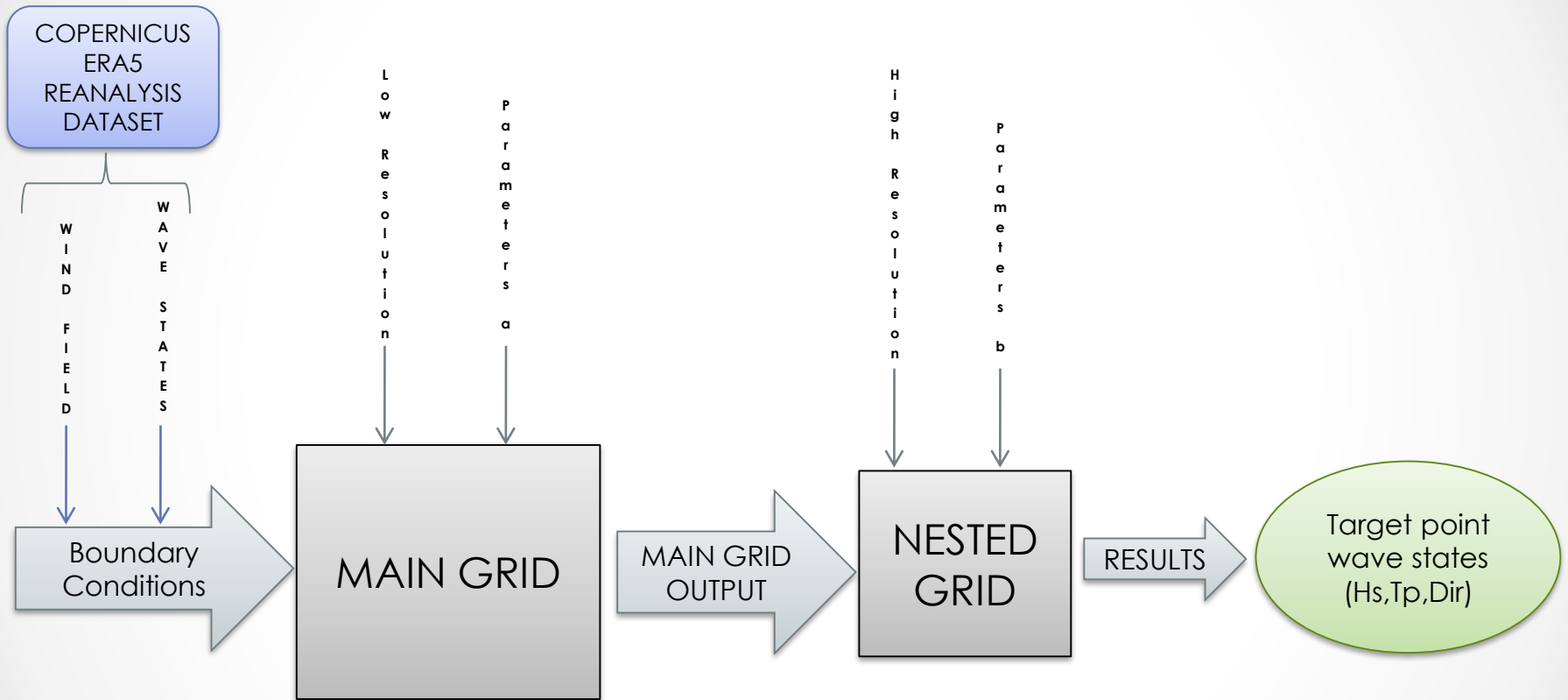
Period of study : 01/01/1979 -> 31/07/2019 (40 year)

Modeling software : SWAN (stationary mode)

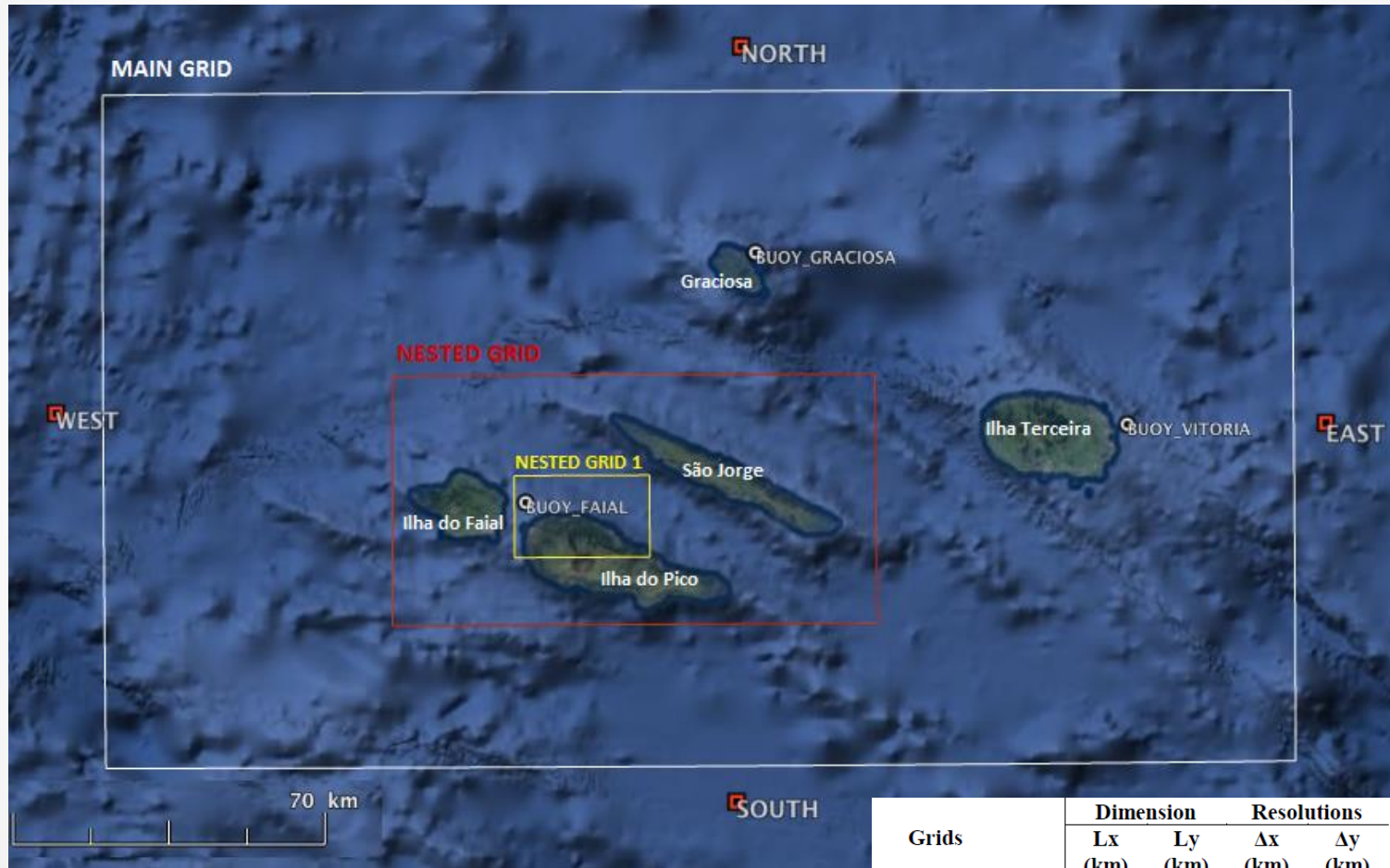
Output SWAN model : wave climate data

Data treatment : Wave energy assessment

SWAN Model



Wave Climate – Azores



Grids	Dimension		Resolutions	
	Lx (km)	Ly (km)	Δx (km)	Δy (km)
Main	265	149	1.2	1.2
Nested	106.8	54.6	0.6	0.6
Nested1	30	18	0.1	0.1

TARGET POINT POSITIONS

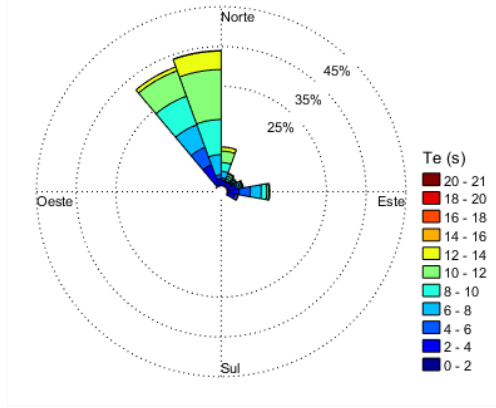
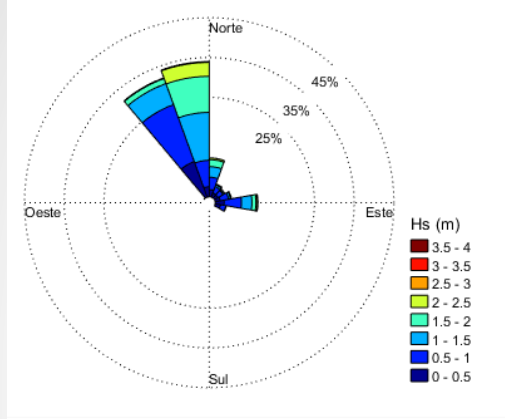


Extraction point depth : 10m



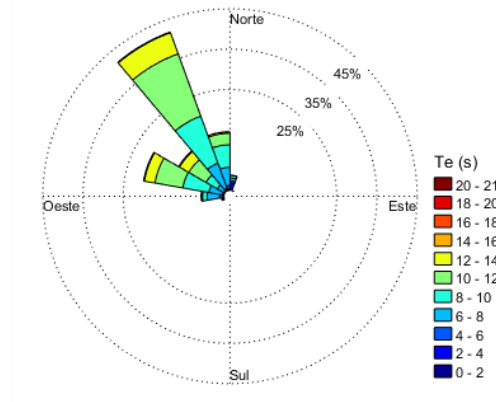
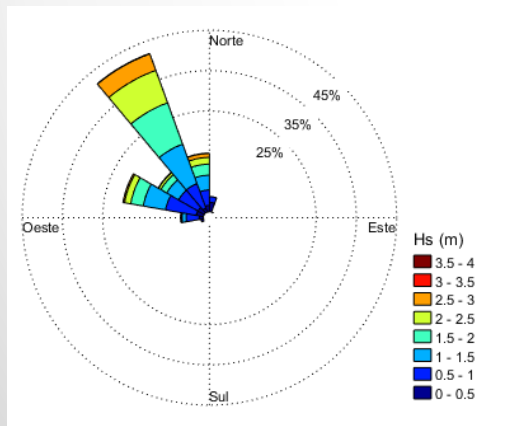
Extraction point depth : 15m

WIND ROSES



Sao Roque

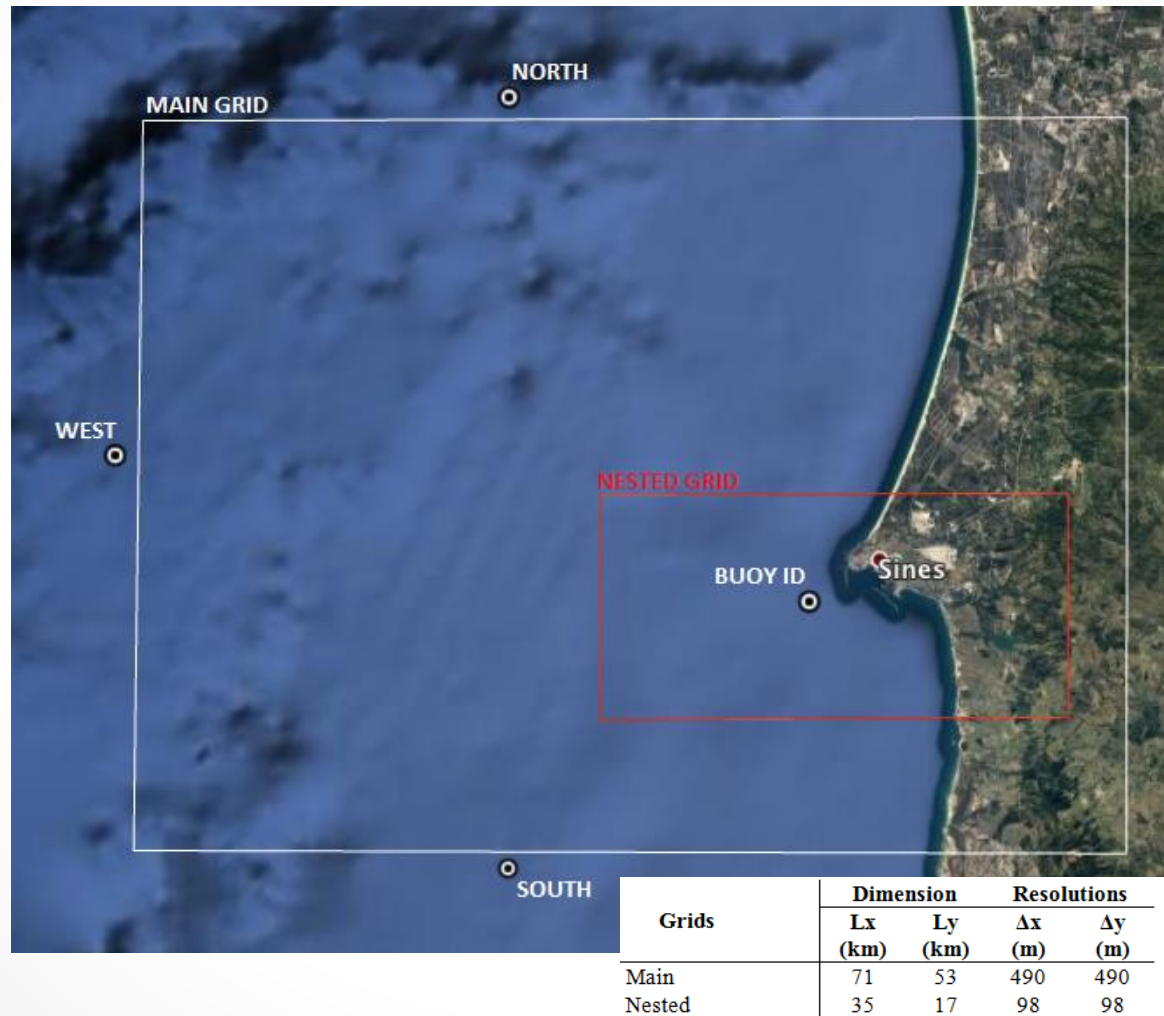
- 90% of incident waves between 320° and 90°
- Hsmax = 11.3m



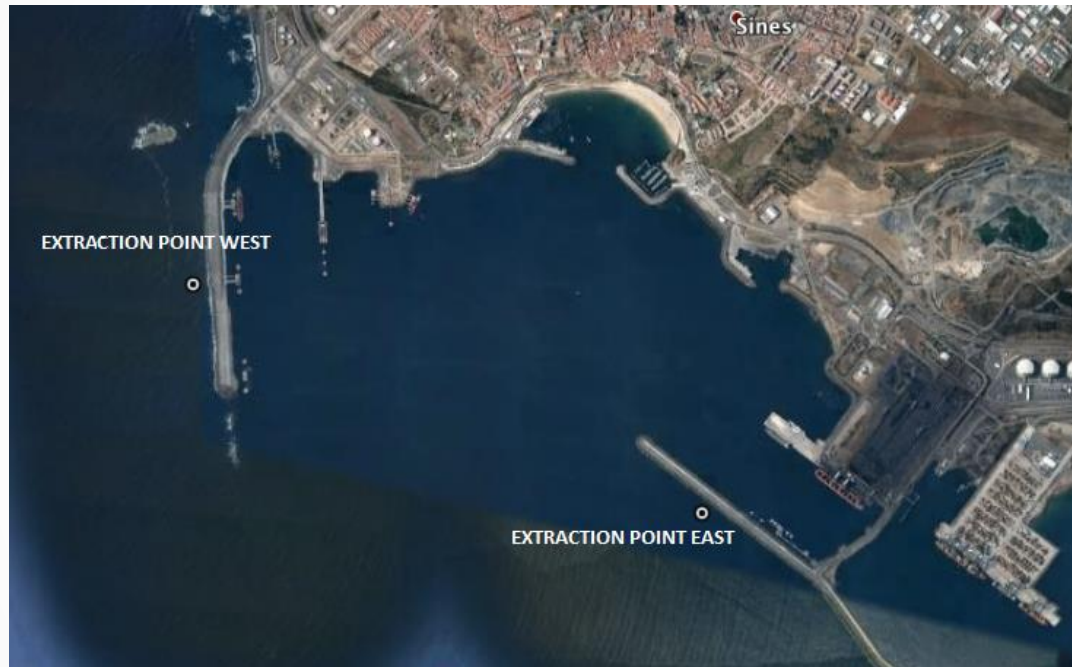
Madalena

- 90% of incident waves between 280° and 340°
- Hsmax = 4.1m

Wave Climate - Sines

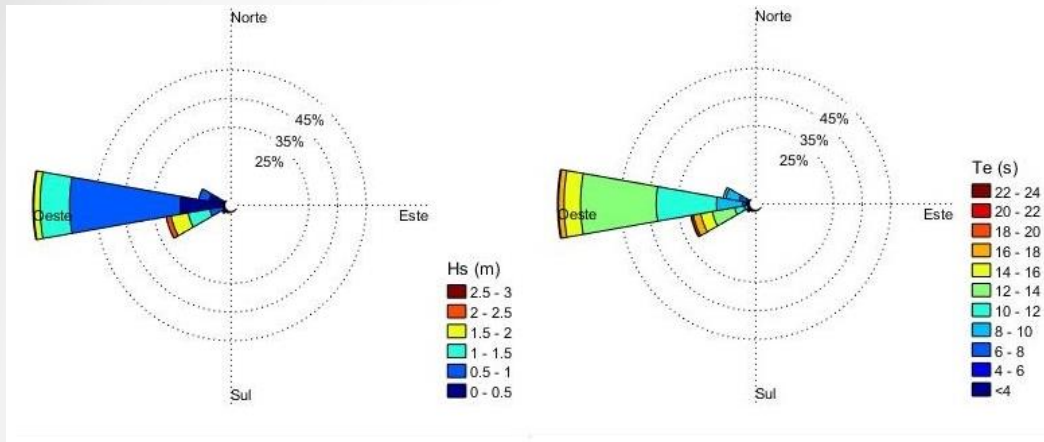


TARGET POINT POSITIONS



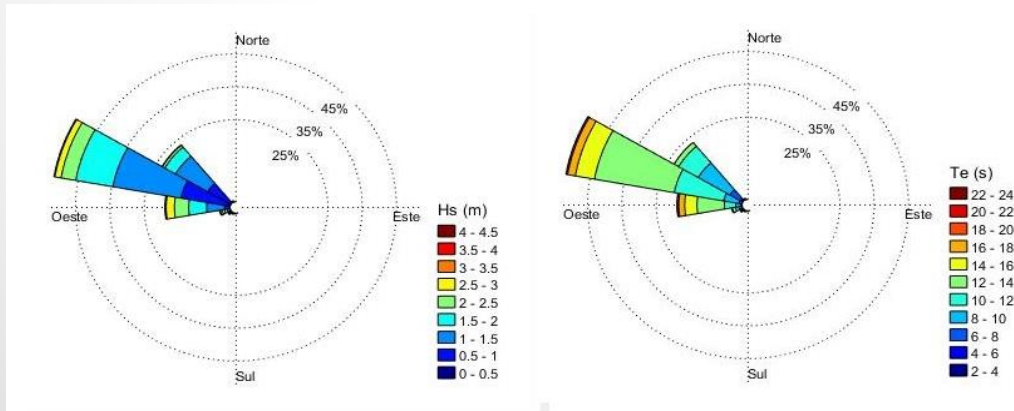
Both points are 50m far from the breakwater and about 30m depth

WIND ROSES



EAST

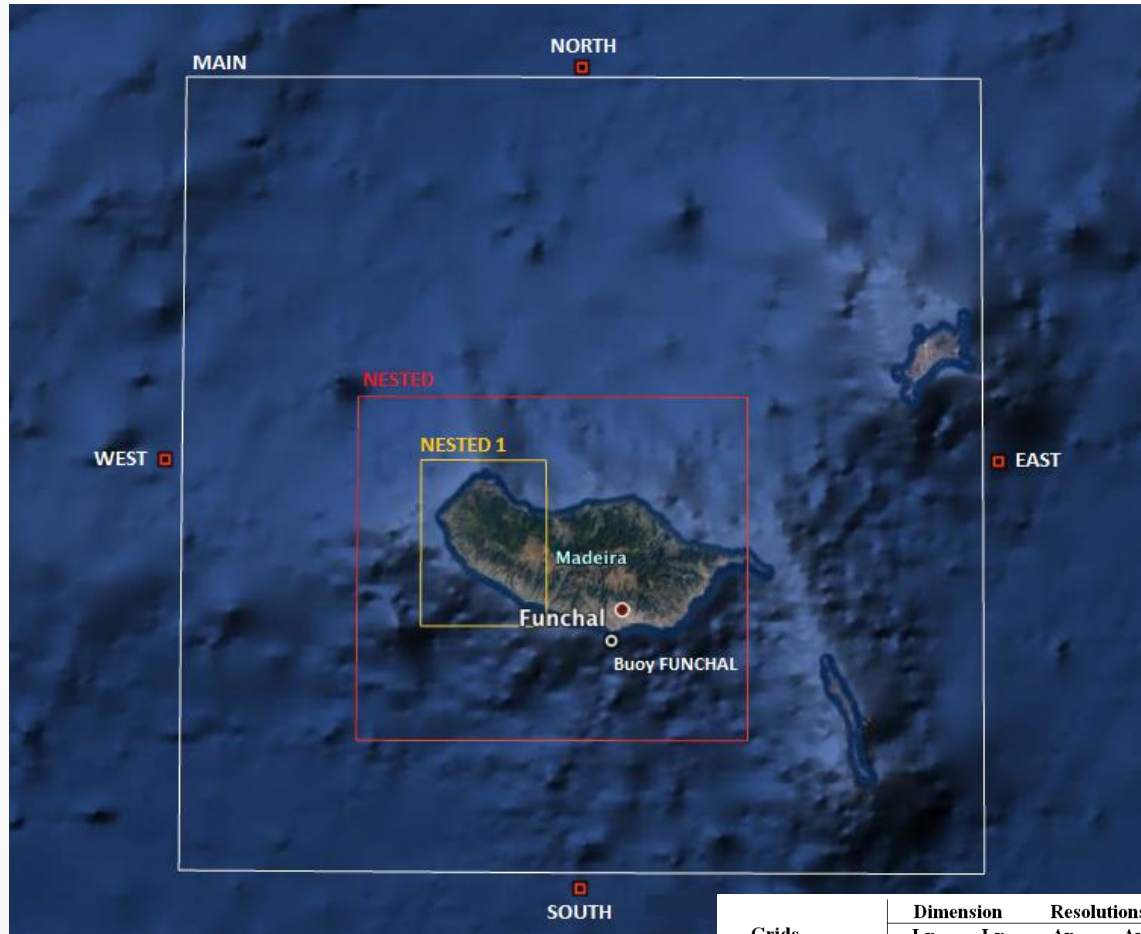
- 99% of incident waves between 240° and 300°
- Hsmax = 6.8m



WEST

- 96% of incident waves between 260° and 320°
- Hsmax = 7.5m

Wave Climate - Madeira



Grids	Dimension		Resolutions	
	Lx (km)	Ly (km)	Δx (m)	Δy (m)
Main	138	135	1200	1200
Nested	69	60	600	600
Nested 1	29	22	100	100

TARGET POINT POSITIONS

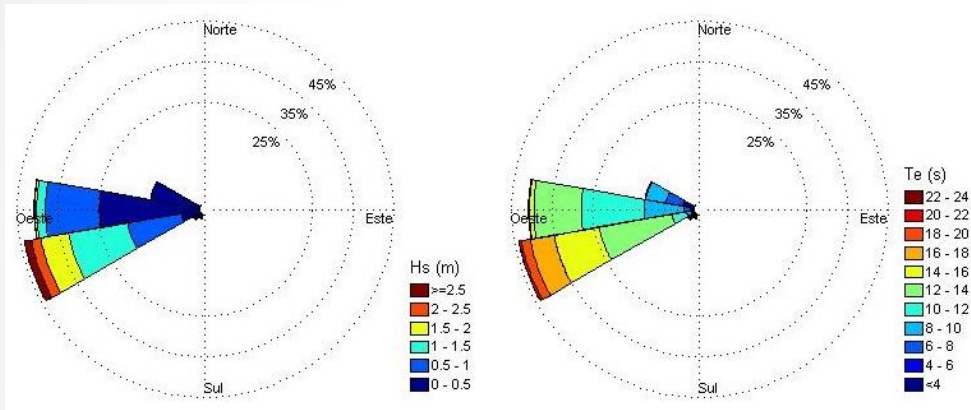


Extraction point depth : 20m



Extraction point depth : 50m

WIND ROSES

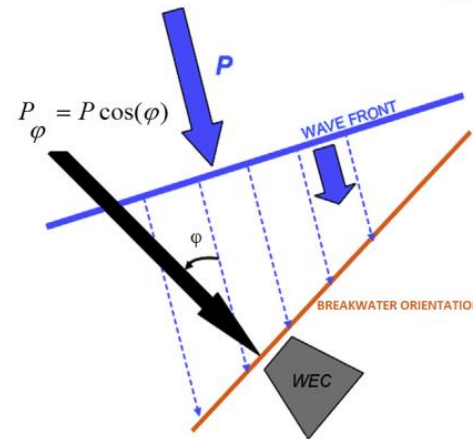


PAUL DO MAR

- 98% of incident waves between 240° and 320°
- Hsmax = 6.4m

Exploitable Energy

Methodology



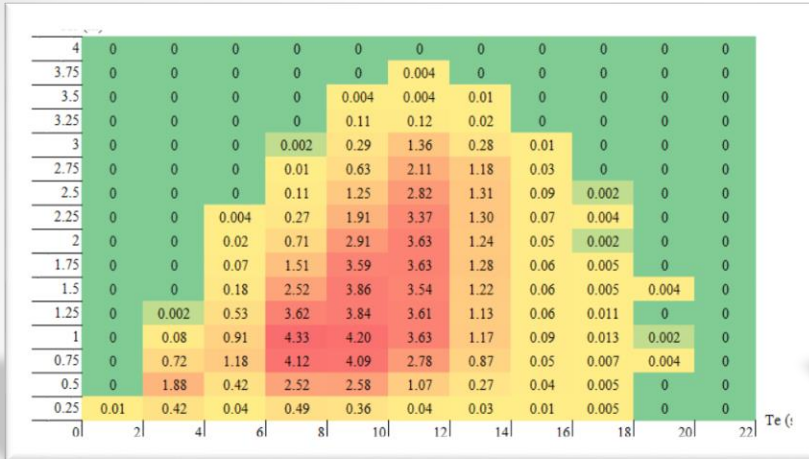
$$P = \frac{\rho g^2}{64\pi} T_e H_s^2 \quad (1)$$

$$P_\phi = P \cos(\phi)$$

$$0 < P_\phi = \frac{\rho g^2}{64\pi} T_e H_s^2 \cos(\phi) < 4 \langle P_\phi \rangle$$

Exploitable Energy

Methodology

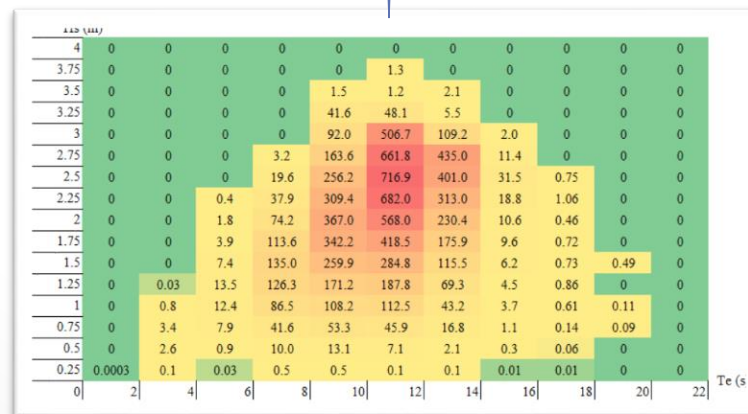


occurrences



mean exploitable energy flux

Mean annual number of hours



mean annual exploitable energy per unit wave crest

Mean annual exploitable energy flux wave front length ($\text{Wm}^{-1}\text{year}^{-1}$)

Hs (m)	0	2	4	6	8	10	12	14	16	18	20	22
4	0	0	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	1.1	0	0	0	0	0	0
3.25	0	0	0	0	0	3.7	0.36	0	0	0	0	0
3	0	0	0.3	2.1	4.7	0	0	0	0	0	0	0
2.75	0	0	2.7	9.6	29.2	11.4	0	0	0	0	0	0
2.5	0	0	2.4	12.7	64.1	105.5	7.9	0	0	0	0	0
2.25	0	0	6.8	25.8	94.2	271.7	122.7	0.7	0	0	0	0
2	0	0.2	15.3	34.3	119.7	347.4	176.6	7.3	0.76	0	0	0
1.75	0	1.3	19.7	50.6	146.8	323.1	131.8	4.8	0	0	0	0
1.5	0	5.2	22.0	64.4	155.3	248.8	90.3	3.7	0	0	0	0
1.25	0	9.8	23.3	79.7	135.8	171.4	56.8	2.7	0.14	0	0	0
1	0	13.5	22.3	57.0	85.2	84.7	31.7	1.3	0.34	0	0	0
0.75	0	14.4	17.4	33.4	34.8	39.5	14.4	0.9	0.10	0.05	0	0
0.5	0.004	12.5	2.3	8.2	9.2	7.7	2.7	0.06	0	0.03	0.03	0
0.25	0.014	0.6	0.03	0.3	0.5	0.2	0.1	0.003	0.003	0	0	0
0	0	2	4	6	8	10	12	14	16	18	20	22

Sao Roque

- Overall energy : **3724MWm⁻¹year⁻¹**
- **80%** of it, is produced by **43%** of the sea state occurrences
Hs between 1 and 2.25m & Te between 6 and 14s

Hs (m)	0	2	4	6	8	10	12	14	16	18	20	22
4	0	0	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	1.3	0	0	0	0	0
3.5	0	0	0	0	0	1.5	1.2	2.1	0	0	0	0
3.25	0	0	0	0	0	41.6	48.1	5.5	0	0	0	0
3	0	0	0	0	0	92.0	506.7	109.2	2.0	0	0	0
2.75	0	0	0	0	3.2	163.6	661.8	435.0	11.4	0	0	0
2.5	0	0	0	0	19.6	256.2	716.9	401.0	31.5	0.75	0	0
2.25	0	0	0.4	37.9	309.4	682.0	313.0	18.8	1.06	0	0	0
2	0	0	1.8	74.2	367.0	568.0	230.4	10.6	0.46	0	0	0
1.75	0	0	3.9	113.6	342.2	418.5	175.9	9.6	0.72	0	0	0
1.5	0	0	7.4	135.0	259.9	284.8	115.5	6.2	0.73	0.49	0	0
1.25	0	0.03	13.5	126.3	171.2	187.8	69.3	4.5	0.86	0	0	0
1	0	0.8	12.4	86.5	108.2	112.5	43.2	3.7	0.61	0.11	0	0
0.75	0	3.4	7.9	41.6	53.3	45.9	16.8	1.1	0.14	0.09	0	0
0.5	0	2.6	0.9	10.0	13.1	7.1	2.1	0.3	0.06	0	0	0
0.25	0.0003	0.1	0.03	0.5	0.5	0.1	0.1	0.01	0.01	0	0	0
0	0	2	4	6	8	10	12	14	16	18	20	22

Madalena

- Overall energy : is **9150MWm⁻¹year⁻¹**
- **80%** of it, is produced by **40%** of the sea state occurrences
Hs between 1.25 and 3m & Te between 8 and 14s

Mean annual exploitable energy flux wave front length ($\text{Wm}^{-1}\text{year}^{-1}$)

Hs (m)													
4	0	0	0	0	0	0	0	0	0	0	0	0	
3.75	0	0	0	0	0	0	0	0	0	0	0	0	
3.5	0	0	0	0	0	0	0	0	0	0	0	0	
3.25	0	0	0	0	0.0	0	0	0	0	0	0	0	
3	0	0	0.0	0.9	0.4	0	0	0	0	0	0	0	
2.75	0	0	0.0	15.4	10.6	2.6	0.4	0	0	0	0	0	
2.5	0	0	0.3	18.0	37.2	45.9	14.3	5.2	0	0	0	0	
2.25	0	0	1.1	25.4	41.3	80.2	88.7	171.0	4.4	0.5	0	0	
2	0	0	2.2	20.6	47.4	97.5	118.7	294.4	36.8	6.6	0	0	
1.75	0	0	4.0	16.9	41.9	115.1	138.5	274.4	29.7	9.7	0.7	0	
1.5	0	0	2.9	16.6	37.0	131.6	154.1	237.4	20.5	5.6	0.5	0	
1.25	0	0.2	2.6	13.8	35.9	159.5	170.5	191.0	14.7	3.6	0.3	0	
1	0	1.3	3.2	13.6	49.1	181.6	158.6	99.5	8.34	1.8	0.2	0	
0.75	0.04	2.4	2.8	15.5	63.7	159.6	55.6	29.7	2.36	0.6	0.3	0	
0.5	0.14	0.4	1.1	9.6	29.7	30.3	6.2	3.29	0.267024	0.08	0.02	0	
0.25	0.02	0.002	0.01	0.2	0.7	0.3	0.05	0.02	0	0	0	0	
0	1	3	5	7	9	11	13	15	17	19	21	23	Te (s)

EAST

- Overall energy : **3950MWm⁻¹year⁻¹**
- **80%** of it, is produced by **63%** of the sea state occurrences
Hs between 0.5 and 2.25m & Te between 9 and 17s

Hs (m)												
4.5	0	0	0	0	1.0	0	0	0	0	0	0	0
4.25	0	0	0	1.0	0	0	0	0	0	0	0	0
4	0	0	0	5.8	2.9	0	0	0	0	0	0	0
3.75	0	0	0.8	17.3	26.3	2.1	0	0	0	0	0	0
3.5	0	0	0.6	17.3	63.1	35.2	0	0	0	0	0	0
3.25	0	0	0.4	29.8	59.6	214.5	60.8	0	0	0	0	0
3	0	0	3.1	36.4	89.2	292.6	297.0	193.3	9.3	0	0	0
2.75	0	0	9.5	45.8	109.5	418.2	338.6	282.6	56.8	6.1	0	0
2.5	0	0	11.6	50.3	126.6	490.7	404.6	228.3	47.0	16.3	2.0	0
2.25	0	0	20.4	66.9	158.7	607.8	385.6	196.7	35.8	12.6	0.9	0
2	0	1.0	24.2	95.5	197.5	781.7	347.6	128.9	34.6	6.6	1.1	0
1.75	0	4.1	33.4	115.6	250.2	819.8	231.0	85.8	25.0	5.4	1.3	0
1.5	0	7.9	45.7	139.7	358.7	695.6	134.6	59.4	19.1	5.4	0.7	0
1.25	0.1	6.8	48.5	173.4	362.9	396.6	68.6	28.8	9.8	2.1	0.6	0
1	0.3	3.5	25.6	113.8	187.9	147.6	22.9	9.5	2.3	0.7	0.1	0
0.75	0.1	1.1	6.1	36.4	44.2	26.7	4.5	2.0	0.5	0.2	0.05	0
0.5	0.03	0.1	0.3	1.9	1.9	1.5	0.1	0.2	0.03	0.02	0	0
0.25	0.001	0	0.001	0.0024	0.0004	0	0.01	0	0	0	0	0
0	2	4	6	8	10	12	14	16	18	20	22	Te (s)

WEST

- Overall energy : is **11987MWm⁻¹year⁻¹**
- **80%** of it, is produced by **65%** of the sea state occurrences
Hs between 1 and 3m & Te between 8 and 16s

■ Mean annual exploitable energy flux wave front length ($\text{MWm}^{-1}\text{year}^{-1}$)

Hs (m)													Te (s)
	0	2	4	6	8	10	12	14	16	18	20	22	
2.75	0	0	0	0	1.1	1.1	0	0	0	0	0	0	0
2.5	0	0	0	0	6.7	11.0	4.3	0	0	0	0	0	0
2.25	0	0	0	0	9.7	15.2	24.0	20.4	0.7	0	0	0	0
2	0	0	0	0	10.5	15.5	28.2	101.3	97.7	96.4	11.4	0	0
1.75	0	0	0	0	8.6	14.3	36.6	141.3	196.7	209.7	86.6	13.9	1.1
1.5	0	0	0	1.2	8.1	14.2	40.5	204.7	261.7	162.3	41.2	7.8	0.6
1.25	0	0.1	0.7	0.7	5.2	15.6	45.3	268.3	220.3	80.5	13.7	3.1	0.5
1	0	0.3	0.4	0.4	3.5	12.4	52.9	231.0	93.9	28.2	6.7	1.9	0.6
0.75	0	0.7	0.1	0.1	3.0	11.8	49.5	157.5	36.6	9.0	1.9	0.1	0.2
0.5	0	1.6	0.04	0.04	3.6	20.2	46.9	45.4	6.2	1.4	0.4	0.1	0.01
0.25	0.001	0.6	0.01	0.01	2.0	5.1	3.0	0.8	0.1	0.03	0.01	0	0
	0	2	4	6	8	10	12	14	16	18	20	22	24

PAUL DO MAR

- Overall energy : is **3399** $\text{MWm}^{-1}\text{year}^{-1}$
- **80%** of it, is produced by **48%** of the sea state occurrences
Hs between 0.25 and 2m & Te between 12 and 18s

Variability

- Coefficient Of Variation $COV(P) = \frac{\sigma(P(t))}{\mu(P(t))}$
- Seasonal Variability index $SV = \frac{P_{smax} - P_{smin}}{P_{year}}$
- Inter-Annual Variability $IAV = \frac{\sigma_{\mu(P(t))}}{\mu(P(t))}$

SUMMARY

	São Roque	Madalena	Sines West	Sines East	Seixal	Paul do Mar
Distance from the breakwater	30m	100m	50m	50m	900m	50m
Hsmax	11.3m	4.1m	7.5m	6.8m	-	6.4m
Coefficient of variation	1.56	1.14	1.32	1.84	-	1.64
Seasonal Variability	1.18	1.22	1.32	1.6	-	1.33
Inter-Annual Variability	5.1%	2.7%	3.6%	4.6%	-	3.4%
Values Over Threshold	5.2%	3.5%	4.1%	5.9%	-	5.4%
Exploitable Mean Annual Energy (MWm ⁻¹ year ⁻¹)	3724	9150	11987	3950	-	3399
80% Mean annual energy						
Occurrences (%)	43%	40%	65%	63%	-	48%
Te range	6s – 14s	8s – 14s	8s – 16s	9s – 14s	-	12s – 18s

Thank you