EVALUATION OF THE WAVE ENERGY CONVERSION EFFICIENCY IN VARIOUS COASTAL ENVIRONMENTS

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Objectives and highlights

- The main objective of the present work is to assess the performances of various WEC types that would operate in different coastal environments.
- The transformation efficiency of the wave energy in electricity was evaluated via the load factor and also through an index defined as the ratio between the electric power estimated to be produced by each specific WEC and the expected wave power corresponding to the location considered.


OUTLINE
1. Introduction
2. Wave energy close to the Iberian continental coasts of the Atlantic Ocean
3. Wave energy in Archipelagos
4. Wave energy in enclosed seas
5. Discussions and conclusions

1. Introduction

- The way in which the ocean energy devices will perform, as well as their economic viability, is critically linked to their design and moreover they depend directly on the specific environmental conditions characteristic to a certain area. Thus, due to the specific wave climate, one device can perform better than another in a particular coastal area while in another nearshore area the situation might be completely reversed.

- Portugal and Spain are among the European countries with relevant potential in terms of wave energy. This is because they have a long coast and they are neighboured by a large stretch of ocean to the west. As it is known, the waves are usually stronger close to the western coasts of the continents due to the general wind blowing patterns oriented from west to east.

- Some demonstration projects are operational in both the Spanish and the Portuguese continental nearshores and also several other projects are under study.

- According to the European Ocean Energy Road Map 2010-2050, the potential installed wave energy conversion capacity by 2050 would be greater than the combined capacity of wind and solar electricity.

2. Wave energy on the Iberian continental coast of OA

Description of the WECs considered

- **In intermediate and deep water conditions:**
  - **Seabased AB – P_{nom} = 15kW**
  - **Oceantec – P_{nom} = 500kW**
  - **Pelamis – P_{nom} = 750kW**
  - **Pontoon Power Converter (PPC) – P_{nom} = 3619kW**
  - **Wave Dragon – P_{nom} = 5900kW**

Small-size
Medium-size
Large-size

- **In shallow water conditions:**
  - **Ceto I – P_{nom} = 260kW**
  - **Wave Star – P_{nom} = 2709kW**
  - **Oyster – P_{nom} = 291kW**
  - **Oyster 2 – P_{nom} = 3332kW**
  - **Seawave Slot-Cone Generator (SSG) – P_{nom} = 20000kW**

Small-size
Medium-size
Large-size

Analysis of model data

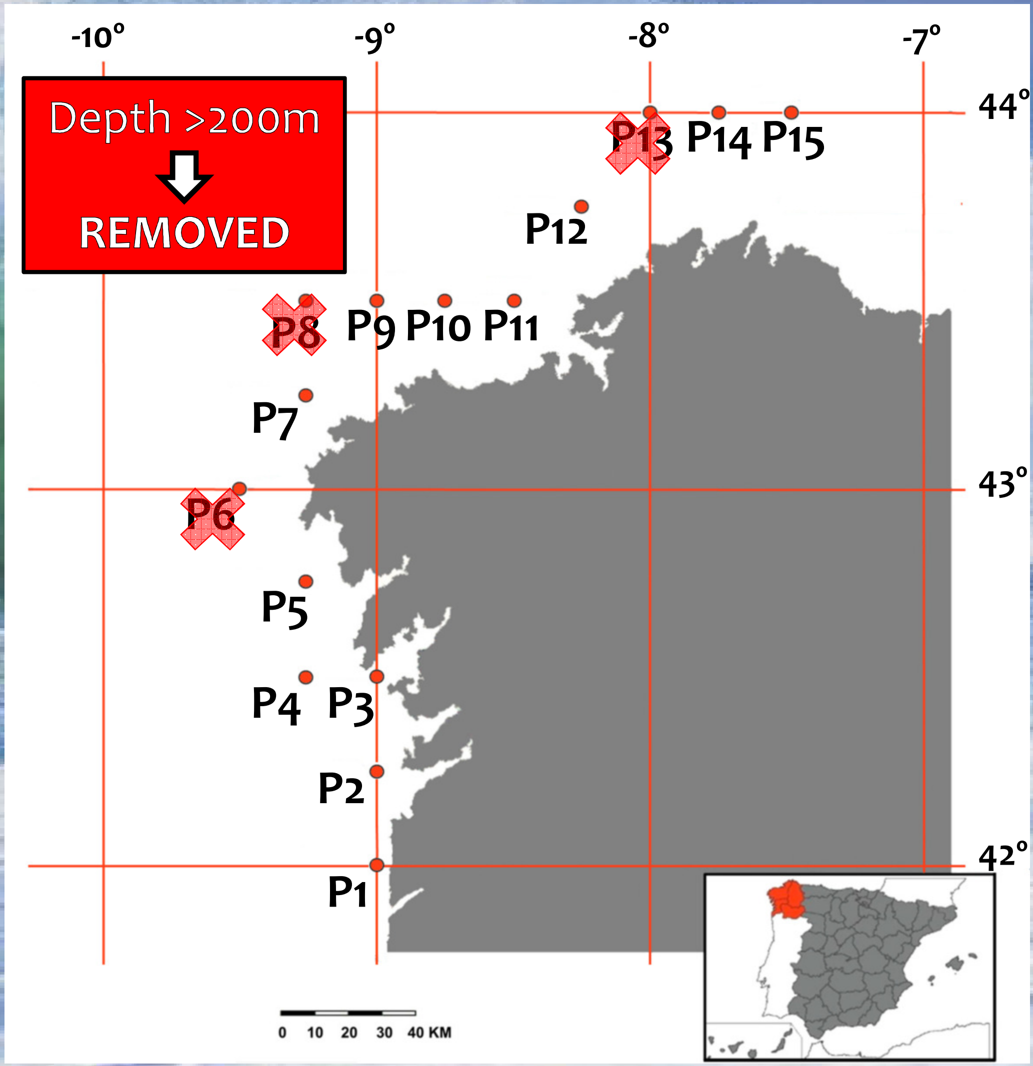
Analysis of WAM data

- **It was carried out using a numerical data set composed of hindcast wind, sea level and wave data for a period of 41 years (1960-2000) with a three-hourly frequency and which belong to the SIMAR-44 data set, provided by Puertos del Estado (Spain's State Ports).**
  - **Wave data was computed with a WAM numerical model**
  - **WAM numerical model was forced with wind data obtained with the regional atmospheric model REMO.**
- **Fifteen reference points have been used in the present analysis.**
- **Results have been structured in total and wintertime periods.** **(<u>Wintertime</u>: 6-month period <u>from October to March</u>).**

Analysis of model data

Analysis of WAM data

Points	Coordinates	Depth (m)
P1	-9.00ºW 42.00ºN	100
P2	-9.00ºW 42.25ºN	110
P3	-9.00ºW 42.50ºN	20
P4	-9.25ºW 42.50ºN	139
P5	-9.25ºW 42.75ºN	80
P6	-9.50ºW 43.00ºN	212
P7	-9.25ºW 43.25ºN	120
P8	-9.25ºW 43.50ºN	400
P9	-9.00ºW 43.50ºN	177
P10	-8.75ºW 43.50ºN	140
P11	-8.50ºW 43.50ºN	110
P12	-8.25ºW 43.75ºN	125
P13	-8.00ºW 44.00ºN	270
P14	-7.75ºW 44.00ºN	135
P15	-7.50ºW 44.00ºN	190



Analysis of model data

Analysis of WAM data

Average values of the main parameters at the twelve reference points to study. Valid results for a 41-year period (1960-2000)

Points	H_s med (m)		T_e med (s)		T_p med (s)		*Dir* med (grad)	
Period	TT	WT	TT	WT	TT	WT	TT	WT
P1	2.00	2.50	9.91	11.14	11.01	12.38	291.88	284.90
P2	1.85	2.34	9.34	11.19	11.04	12.43	287.53	280.84
P3	1.58	2.10	10.34	11.54	11.49	12.82	271.59	266.82
P4	2.21	2.78	9.95	11.17	11.05	12.41	296.21	288.47
P5	2.05	2.60	9.92	11.10	11.02	12.33	291.21	284.33
P7	2.51	3.13	9.76	11.09	10.84	12.32	260.55	271.33
P9	2.57	3.21	9.77	11.12	10.85	12.35	255.32	265.77
P10	2.44	3.05	9.82	11.15	10.91	12.39	261.82	271.44
P11	2.29	2.85	9.90	11.20	11.00	12.44	273.76	281.28
P12	2.47	3.10	9.77	11.09	10.86	12.32	259.10	267.49
P14	2.49	3.14	9.75	11.07	10.83	12.30	255.04	262.26
P15	2.45	3.09	9.75	11.07	10.83	12.30	256.35	263.22

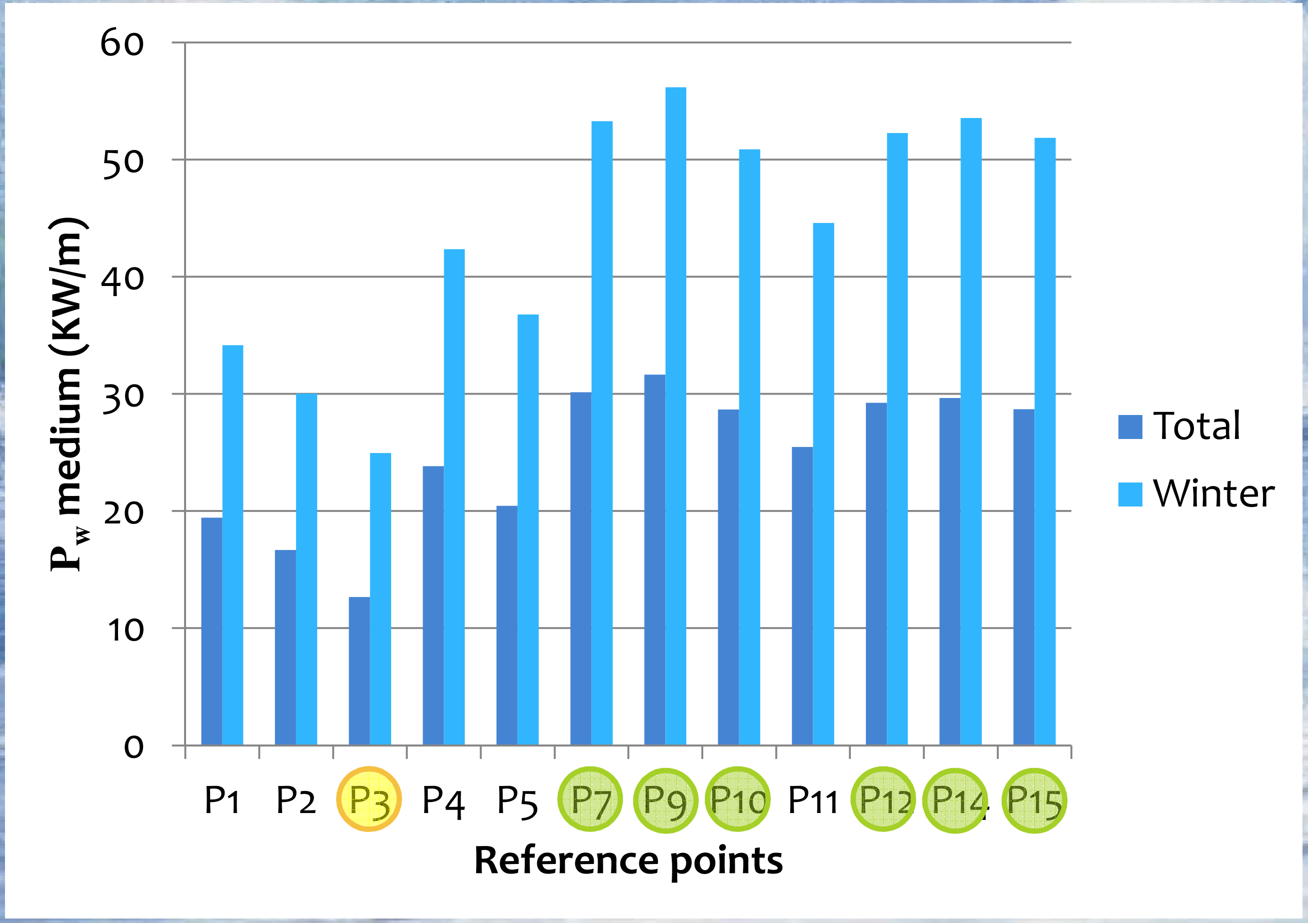
Analysis of model data

Analysis of WAM data

Average values of the wave power at the twelve reference points to study.
Valid results for a 41-year period (1960-2000)

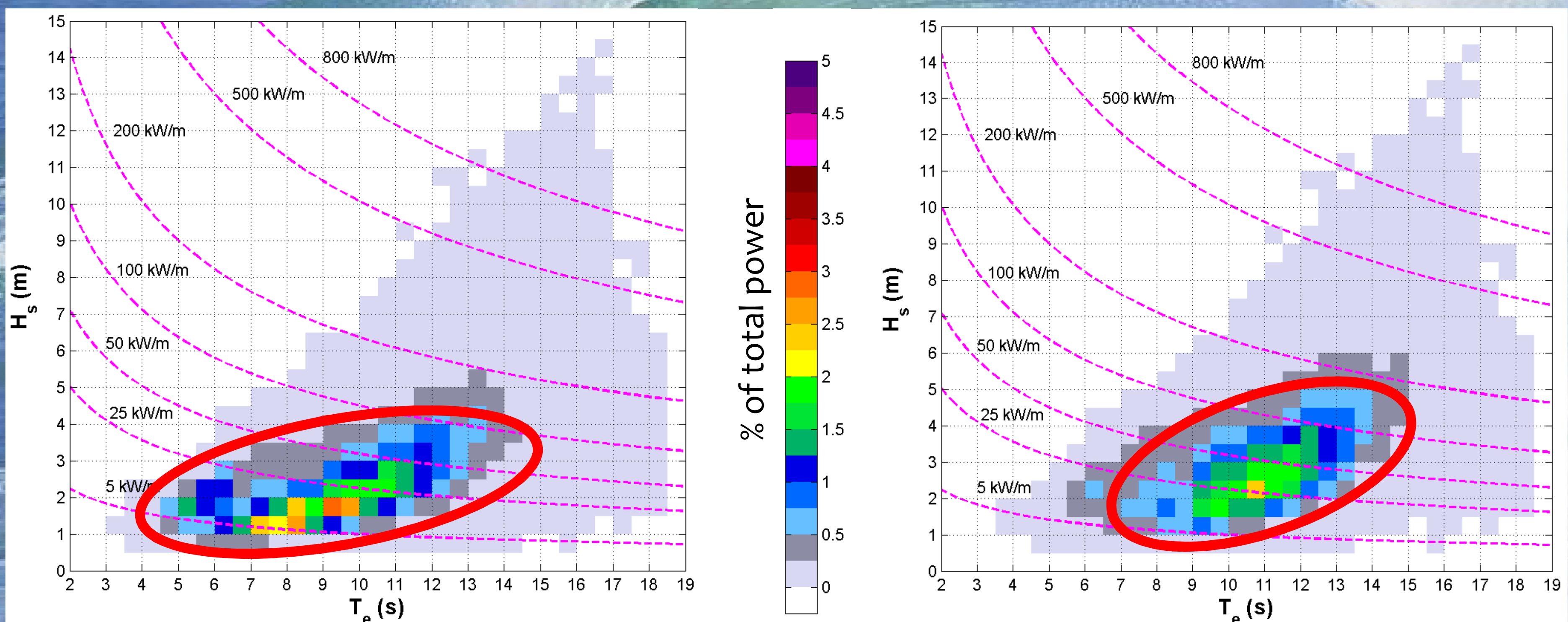
$$P_w = \frac{\rho g^2}{64\pi} T_e H_s^2$$

P_w med (kW/m)	
WT	TT
34.16	19.45
30.06	15.68
24.97	12.76
42.35	23.84
36.81	20.45
53.30	30.17
56.21	31.66
50.89	28.68
44.63	25.47
52.29	29.24
53.55	29.66
51.86	28.71



Estimation of the expected wave power for different WEC systems

Bivariate distributions of ocurrences corresponding to the sea states defined by Hs and Te for the joint time interval 1960-2000 in the reference point P9 – left:TT period, right: WT period.



Estimation of the expected wave power for different WEC systems

Average electric power in kW expected for the devices corresponding to the reference point P3 (up) and the most energetic ones (down).

Period	WECs				
	Ceto I	Oyster	Oyster 2	SSG	Wave Star
Total	6.38	66.08	204.29	986.90	118.84
Winter	9.14	96.76	318.33	1345.50	186.10

Points / Period	WECs									
	Oceantec		Pelamis		Pontoon Power C		Seabased AB		Wave Dragon	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
P7	104.98	103.59	124.47	155.92	236.27	263.67	2.79	3.31	2172.40	2839.50
P9	107.14	106.50	126.59	158.60	239.39	239.36	2.84	3.38	2197.80	2875.00
P10	94.40	94.38	115.57	144.76	219.75	244.45	2.65	3.17	2095.20	2736.40
P12	97.20	100.43	118.37	149.97	224.85	253.12	2.69	3.24	2112.60	2768.60
P14	99.87	105.39	118.06	150.20	227.25	258.50	2.71	3.28	2083.80	2730.90
P15	96.52	102.79	114.24	145.40	221.50	252.10	2.65	3.22	2037.20	2667.60

Estimation of the expected wave power for different WEC systems

- Also, two parameters were calculated:
  - **Load factor:** Average power capture divided by device rating.

$$\eta = \frac{P_E}{P_{nom}}$$

  - **Wave Energy Transformation index (I_{WET}):** ratio of the average electric power to the average wave energy expected in a specific location:

$$I_{WET} = \frac{P_E}{P_W}$$

Estimation of the expected wave power for different WEC systems

Load factor in % for the devices corresponding to the reference point P3 (up) and the most energetic ones (down).

Period	WECs				
	Ceto I	Oyster	Oyster 2	SSG	Wave Star
Total	2.5	22.7	6.1	4.9	4.4
Winter	3.5	33.3	9.6	6.7	6.9

Points / Period	WECs									
	Oceantec		Pelamis		Pontoon Power C		Seabased AB		Wave Dragon	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
P7	21.0	20.7	16.6	20.8	6.5	7.3	18.6	22.1	36.8	48.1
P9	21.4	21.3	16.9	21.1	6.6	6.6	18.9	22.5	37.3	48.7
P10	18.9	18.9	15.4	19.3	6.1	6.8	17.7	21.1	35.5	46.4
P12	19.4	20.1	15.8	20.0	6.2	7.0	17.9	21.6	35.8	46.9
P14	20.0	21.1	15.7	20.0	6.3	7.1	18.1	21.9	35.3	46.3
P15	19.3	20.6	15.2	19.4	6.1	7.0	17.7	21.5	34.5	45.2

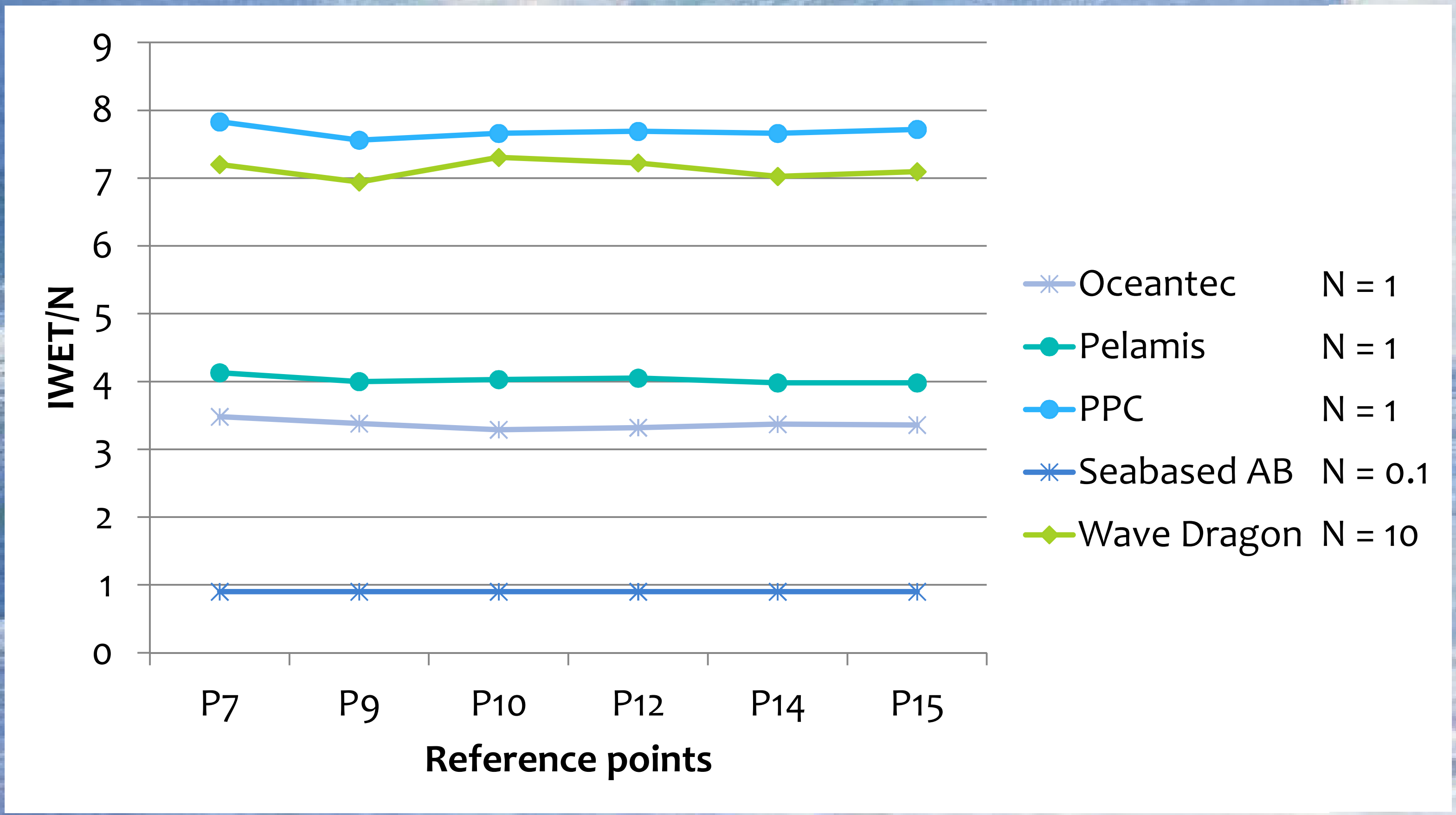
Estimation of the expected wave power for different WEC systems

I_{WET} **index of the WEC devices considered at the six most energetic points**

Points / Period	WECs									
	Oceantec		Pelamis		Pontoon Power C		Seabased AB		Wave Dragon	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
P7	3.48	1.94	4.13	2.93	7.83	4.95	0.09	0.06	72.01	53.27
P9	3.38	1.89	4.00	2.82	7.56	4.26	0.09	0.06	69.42	51.15
P10	3.29	1.85	4.03	2.84	7.66	4.80	0.09	0.06	73.05	53.77
P12	3.32	1.92	4.05	2.87	7.69	4.84	0.09	0.06	72.25	52.95
P14	3.37	1.97	3.98	2.80	7.66	4.83	0.09	0.06	70.26	51.00
P15	3.36	1.98	3.98	2.80	7.72	4.86	0.09	0.06	70.96	51.44

Estimation of the expected wave power for different WEC systems

Variations of the Wave Energy Transformation index (I_{WET}/N) for the WEC devices considered at the six most energetic points in total-time period.

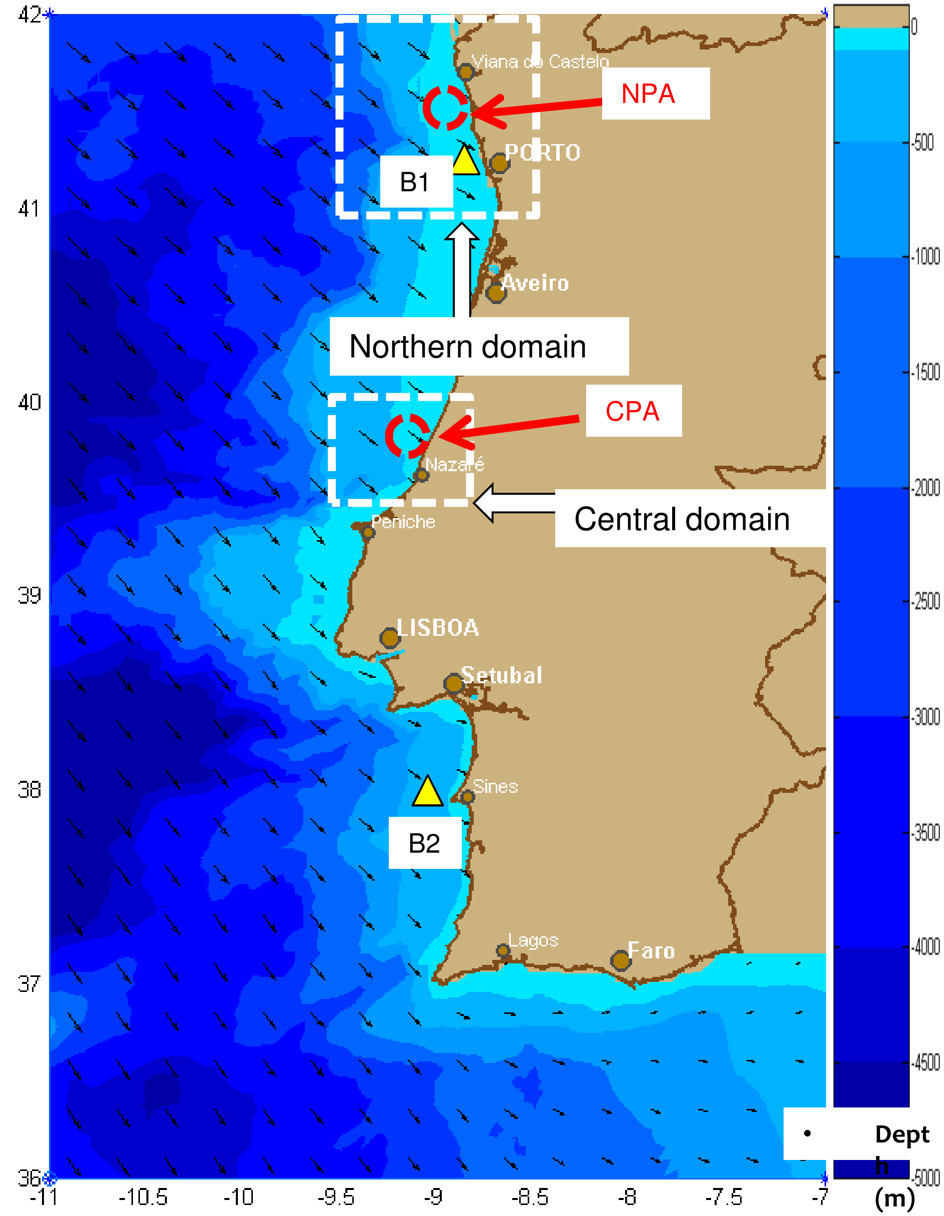


Portuguese nearshore

A wave prediction system based on WW3 for wave generation and on SWAN for coastal transformation was considered. Simulations with the above defined wave prediction system were performed for a three-year time interval: January 2009 – December 2011.

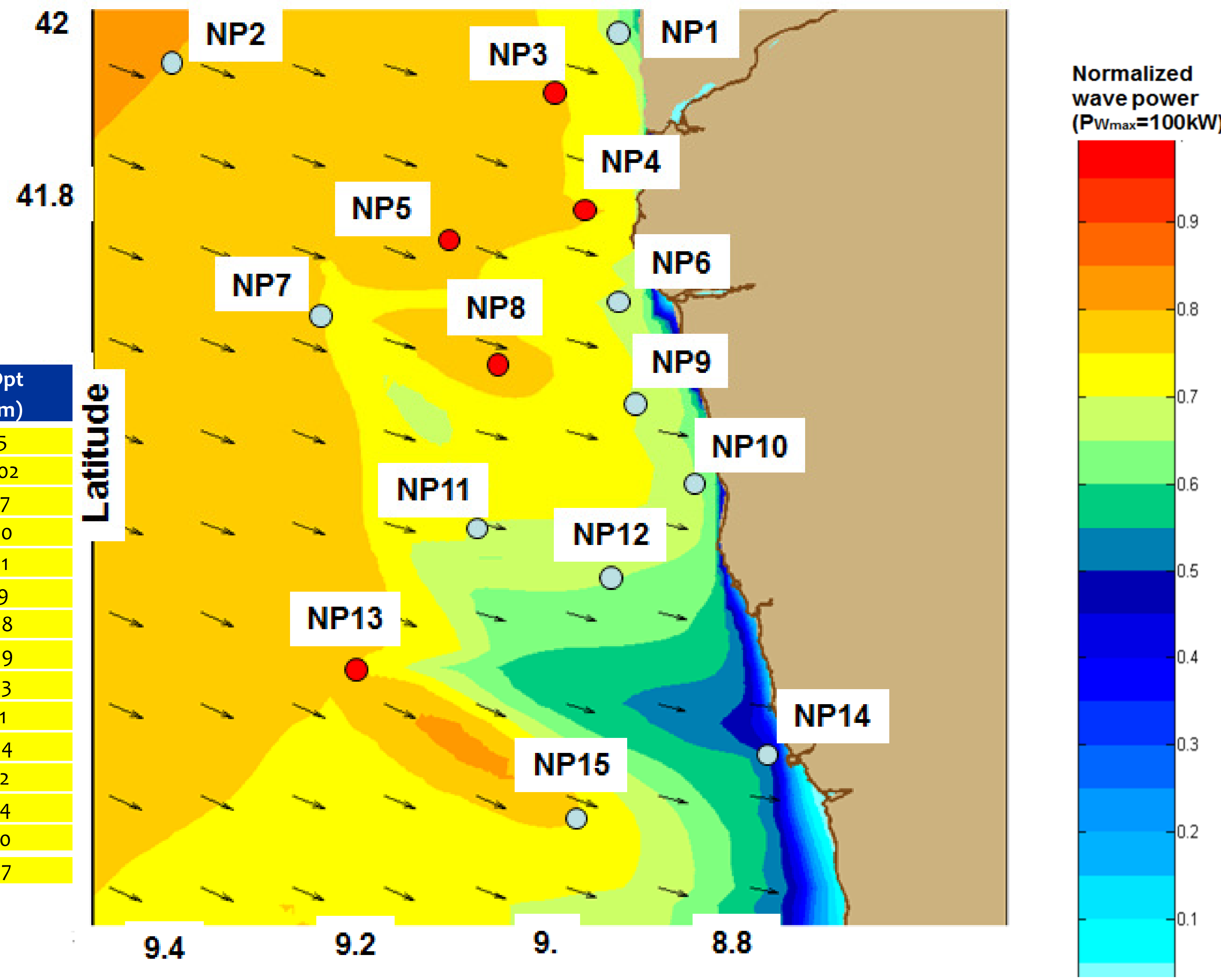
The locations of the two medium resolution computational domains and of the two directional buoys considered for validations, in background the bathymetry of the Portuguese continental nearshore is illustrated.

The positions of the two pilot areas (NPA- northern pilot area and CPA- central pilot area) are indicated with red circles.



Positions of the reference points in the northern computational domain (NP).

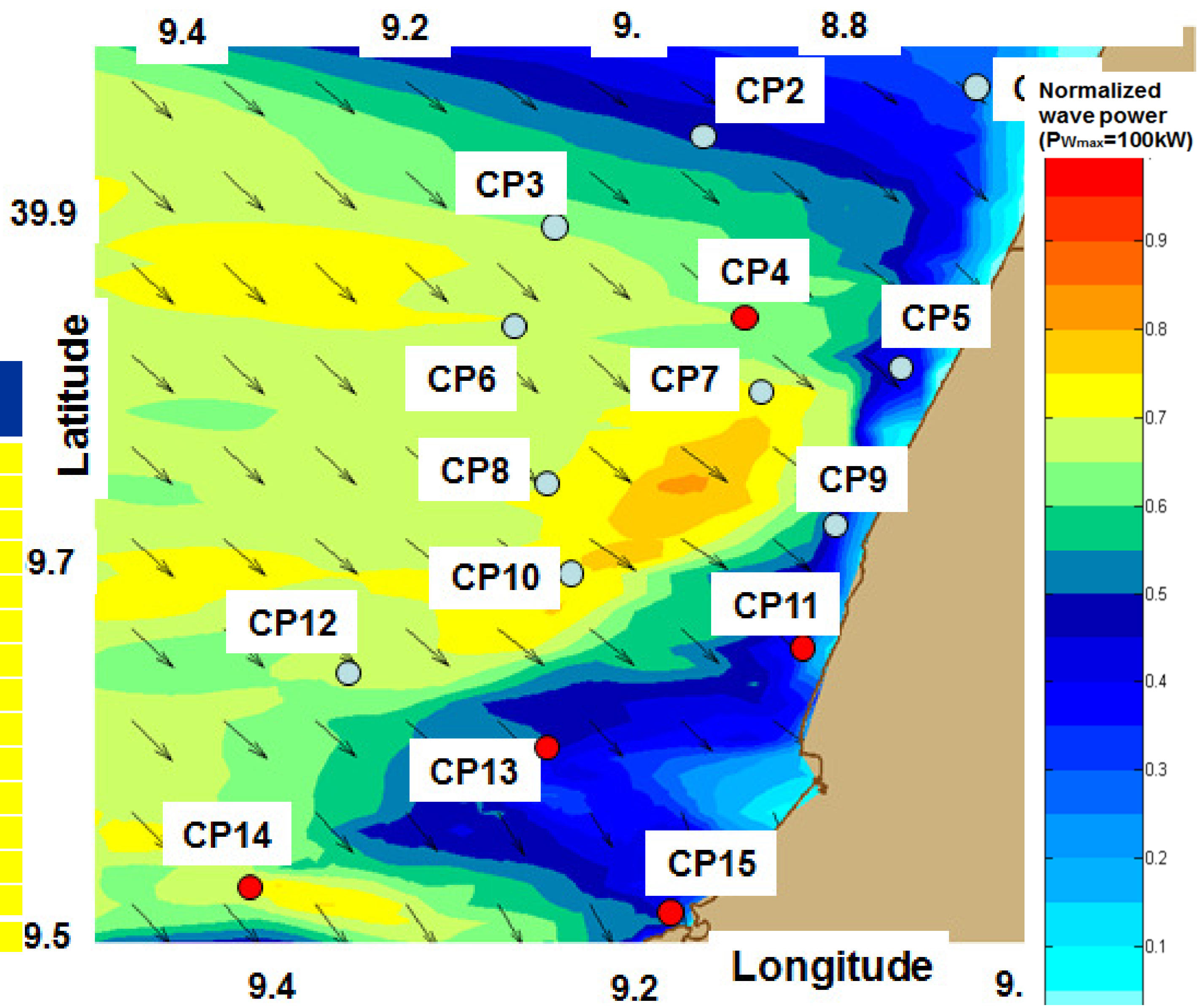
NP	Long (ºW)	Lat (ºN)	Dpt (m)
1	-8.91	41.98	15
2	-9.30	41.94	102
3	-9.01	41.91	57
4	-8.91	41.78	40
5	-9.09	41.7	81
6	-8.90	41.67	19
7	-9.20	41.62	98
8	-9.12	41.57	69
9	-8.94	41.5	63
10	-8.81	41.45	21
11	-9.11	41.41	84
12	-8.92	41.34	72
13	-9.16	41.24	74
14	-8.74	41.2	20
15	-8.96	41.08	67



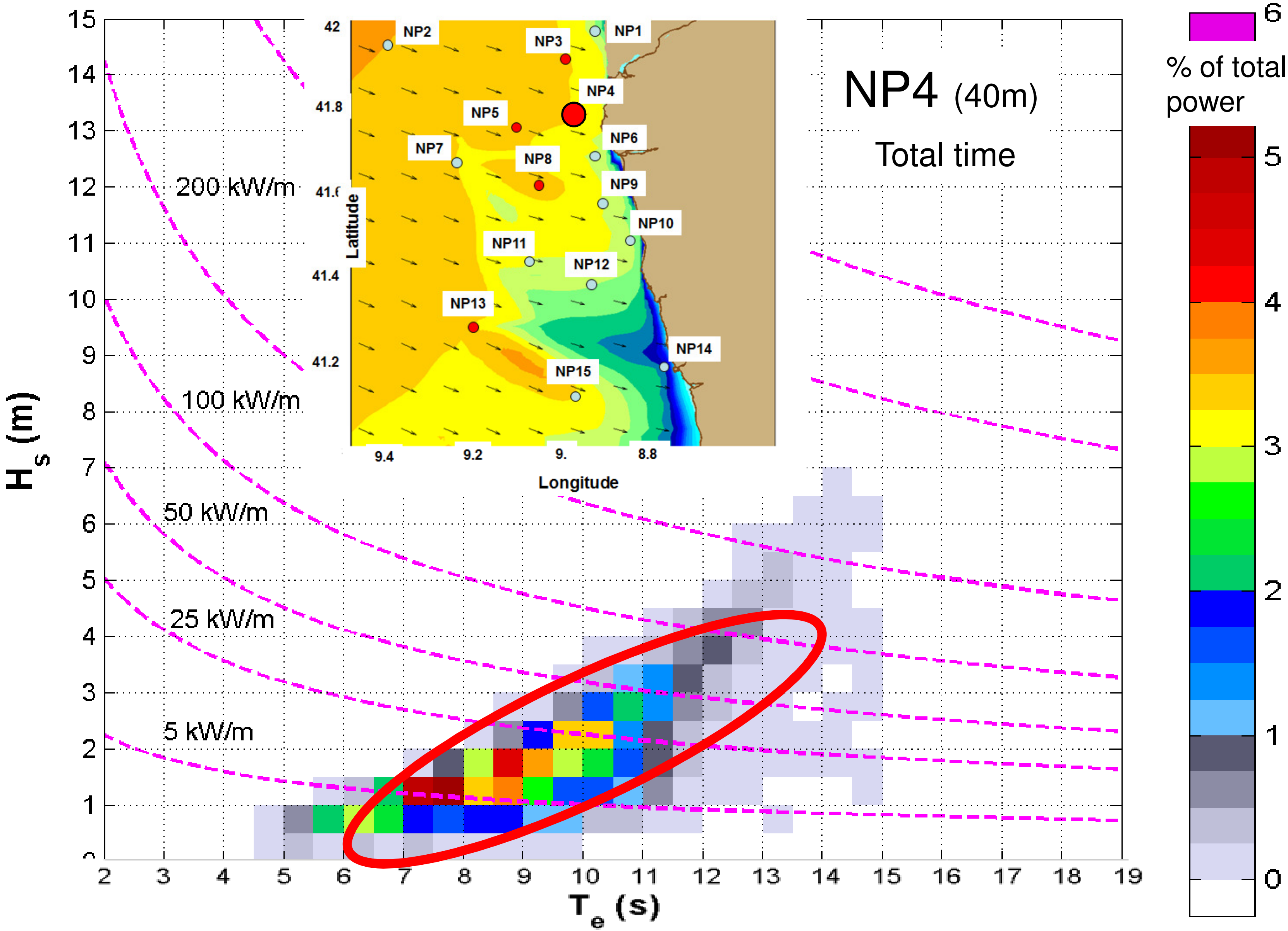
Northern domain, the normalized wave power for the time frame 2010/04/22h18 is represented in background .

Positions of the reference points in the central computational domain (CP).

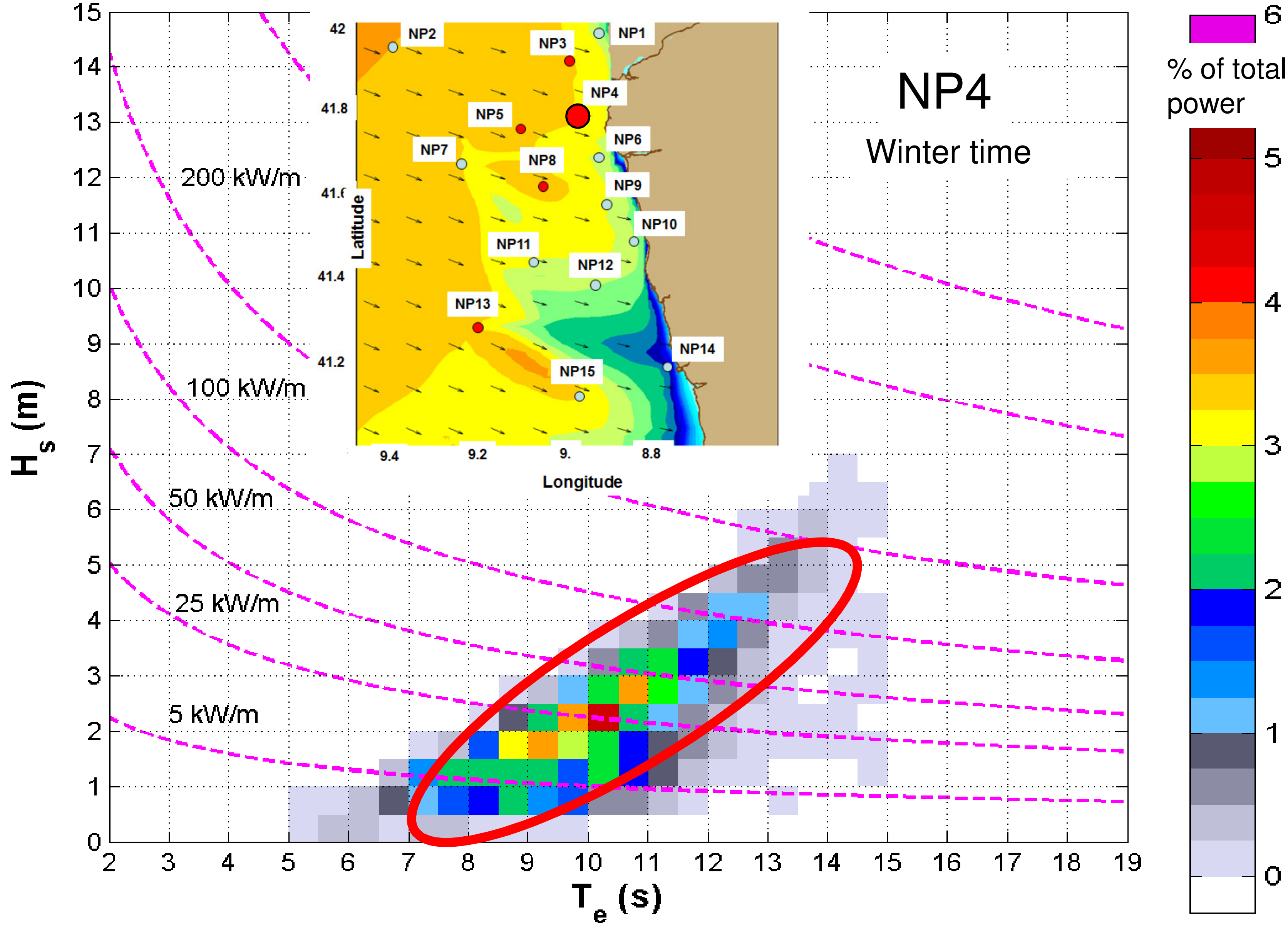
CP	Long (ºW)	Lat (ºN)	Dpt (m)
1	-8.97	39.99	21
2	-9.15	39.95	80
3	-9.25	39.9	94
4	-9.15	39.87	65
5	-9.03	39.84	22
6	-9.27	39.84	100
7	-9.11	39.81	57
8	-9.22	39.75	98
9	-9.07	39.74	21
10	-9.25	39.66	82
11	-9.11	39.62	27
12	-9.36	39.62	58
13	-9.25	39.6	97
14	-9.22	39.54	66
15	-9.16	39.53	32



Central domain, the normalized wave power for the time frame 2010/04/22h18 is represented in background .



NP4 (40m)
Total time
% of total power
200 kW/m
100 kW/m
50 kW/m
25 kW/m
5 kW/m
H_s (m)
T_e (s)
Latitude
Longitude
NP1
NP2
NP3
NP4
NP5
NP6
NP7
NP8
NP9
NP10
NP11
NP12
NP13
NP14
NP15



NP4
Winter time
% of total power
200 kW/m
100 kW/m
50 kW/m
25 kW/m
5 kW/m
H_s (m)
T_e (s)
NP1
NP2
NP3
NP4
NP5
NP6
NP7
NP8
NP9
NP10
NP11
NP12
NP13
NP14
NP15
Latitude
Longitude

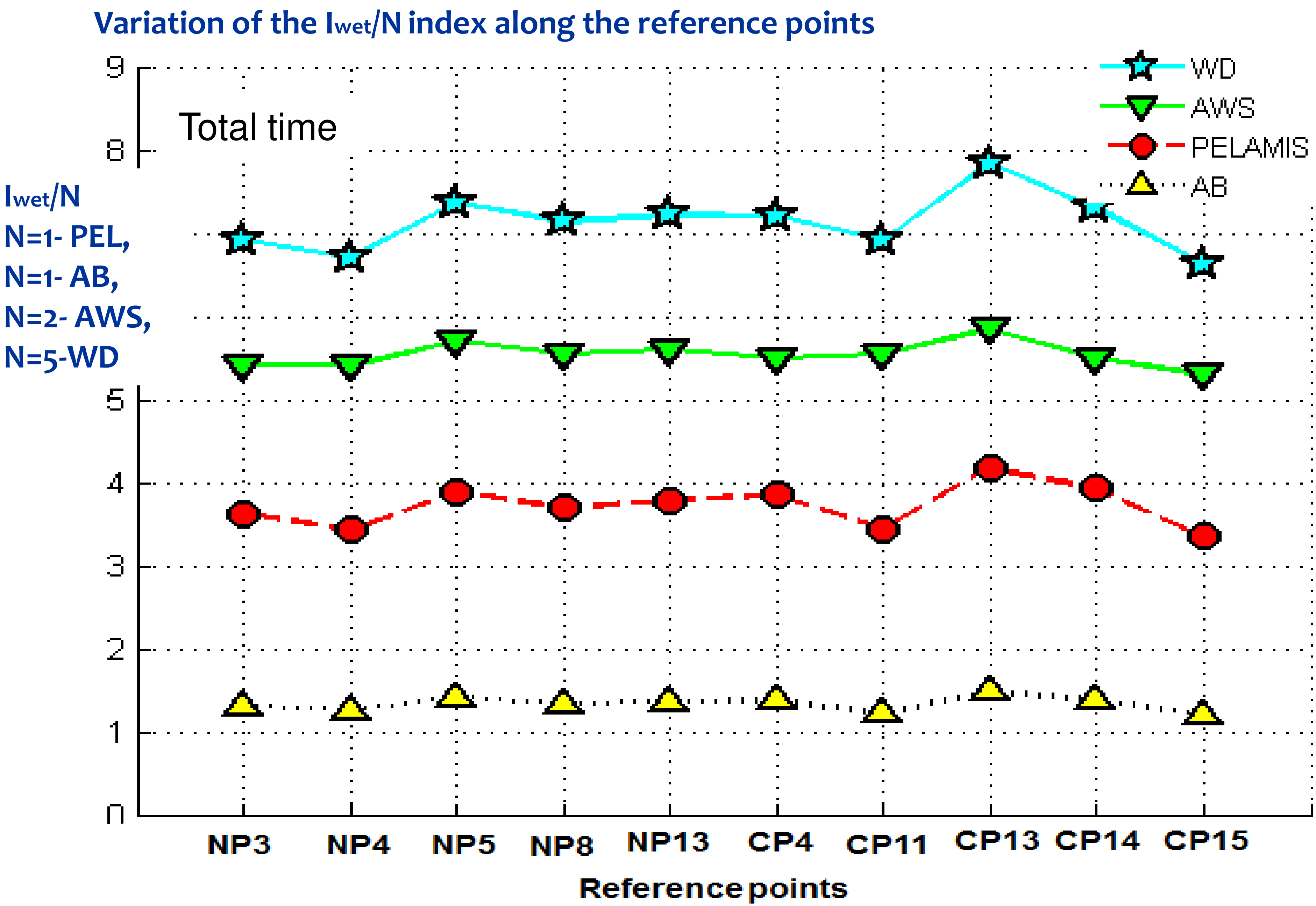
P_E (kW) WD total time [767, 956], winter time [1153,1436],
AWS total time [247, 287], winter time [396, 455],
PEL total time [79, 102] , winter time [109, 142],
AB total time [29, 36], winter time [41, 52].

Total time

Points		WD	AWS	PEL	AB
NP3	P_E(kW)	907.5	282.7	95.1	34.4
	I_{WET}	34.6	10.8	3.63	1.3
NP4	P_E(kW)	766.7	246.9	78.7	28.8
	I_{WET}	33.5	10.8	3.43	1.3
NP5	P_E(kW)	927.9	286.8	98.0	35.7
	I_{WET}	36.8	11.4	3.9	1.4
NP8	P_E(kW)	979.2	302.8	101.1	36.3
	I_{WET}	35.7	11.1	3.7	1.3
NP13	P_E(kW)	957.1	295.9	100.2	36.1
	I_{WET}	36.1	11.2	3.8	1.4
CP4	P_E(kW)	895.8	274.5	95.8	34.1
	I_{WET}	36.0	11.0	3.8	1.4
CP11	P_E(kW)	859.2	275.1	85.4	30.3
	I_{WET}	34.6	11.1	3.4	1.2
CP13	P_E(kW)	955.9	286.9	102.3	36.2
	I_{WET}	39.2	11.7	4.2	1.5
CP14	P_E(kW)	905.2	274.0	97.5	33.9
	I_{WET}	36.5	11.0	3.9	1.4
CP15	P_E(kW)	820.8	262.7	83.1	30.0
	I_{WET}	33.1	10.6	3.3	1.2

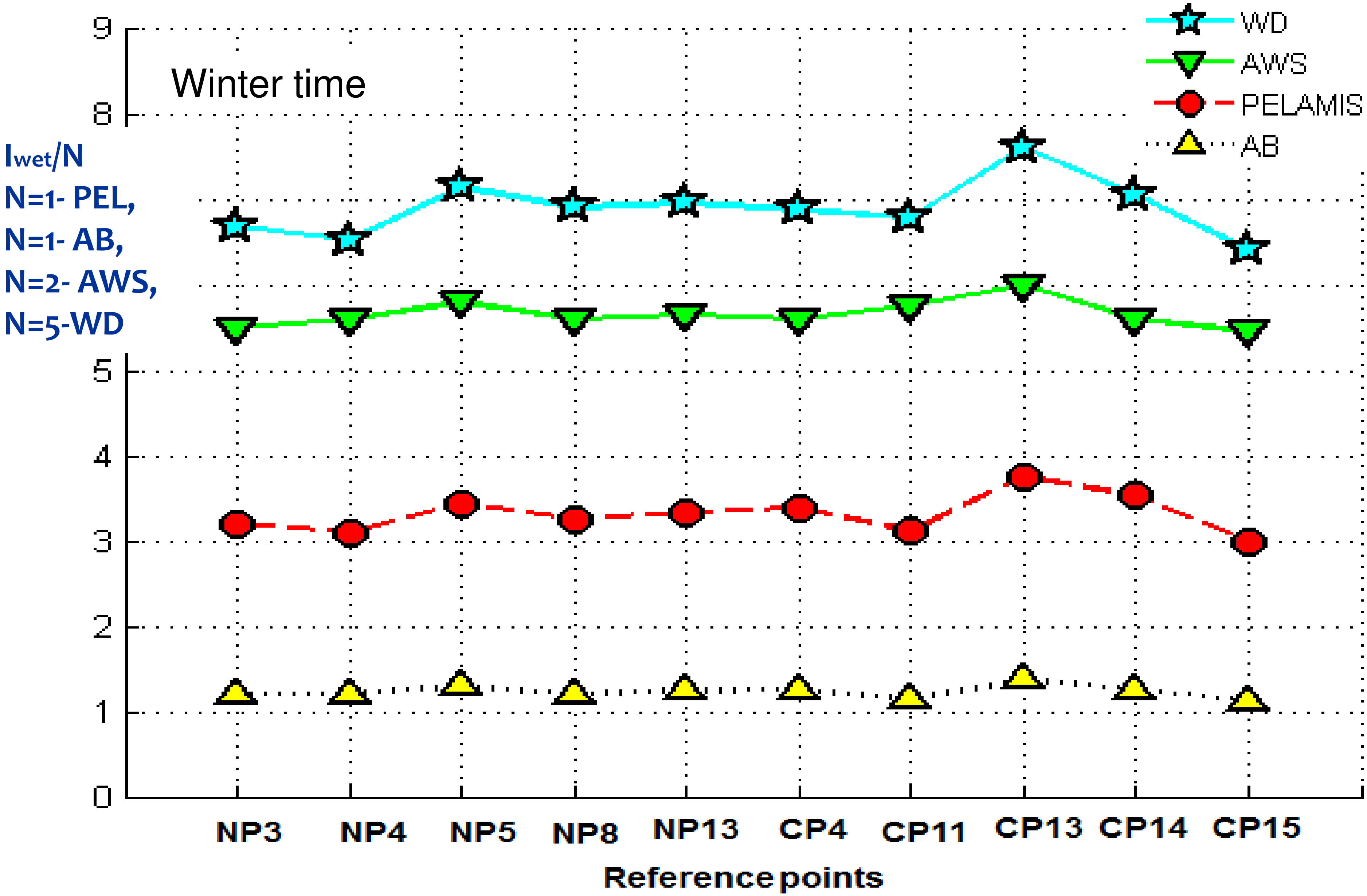
Winter time

Points		WD	AWS	PEL	AB
NP3	P_E	1359	446	130	48.9
	I_{WET}	33.4	11.0	3.2	1.2
NP4	P_E	1153	396	109	41.5
	I_{WET}	32.6	11.2	3.1	1.2
NP5	P_E	1388	451	134	50.6
	I_{WET}	35.7	11.6	3.4	1.3
NP8	P_E	1475	476	139	51.4
	I_{WET}	34.5	11.2	3.2	1.2
NP13	P_E	1440	467	138	51.4
	I_{WET}	34.8	11.3	3.3	1.2
CP4	P_E	1339	436	132	48.6
	I_{WET}	34.4	11.2	3.4	1.2
CP11	P_E	1317	447	121	44.2
	I_{WET}	33.9	11.5	3.1	1.1
CP13	P_E	1436	455	142	51.8
	I_{WET}	38.0	12.0	3.7	1.4
CP14	P_E	1354	433	136	48.3
	I_{WET}	35.2	11.2	3.5	1.3
CP15	P_E	1232	421	115	43.0
	I_{WET}	32.0	10.9	3.0	1.1



Variation of the Iwet/N index along the reference points
Total time
Iwet/N
N=1- PEL,
N=1- AB,
N=2- AWS,
N=5-WD
WD
AWS
PELAMIS
AB
9
8
5
4
3
2
1
0
NP3
NP4
NP5
NP8
NP13
CP4
CP11
CP13
CP14
CP15
Reference points

Variation of the I_{wet}/N index along the reference points



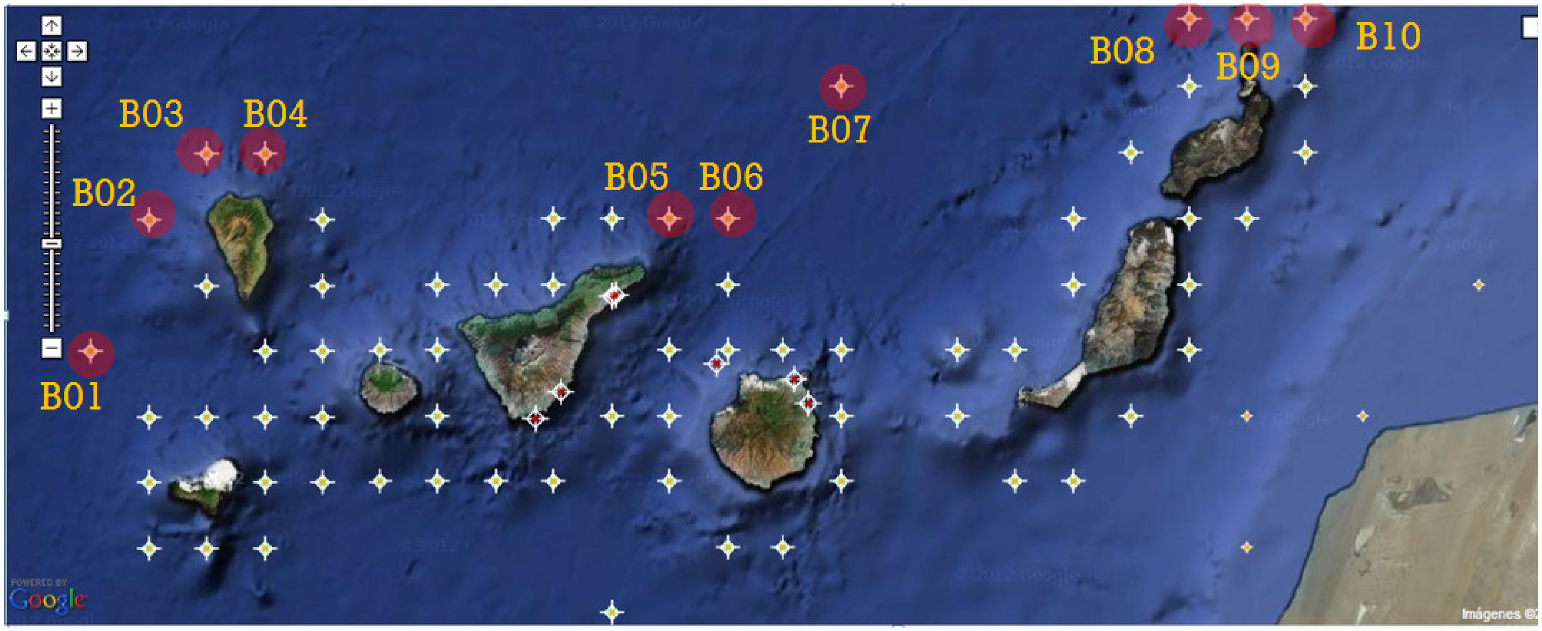
Iwet WD total time [33.1 , 39.2], winter time [32.0 , 38.0],
AWS total time [10.6 , 11.7], winter time [10.9 , 12.0],
PEL total time [3.3, 4.2] , winter time [3.0, 3.7],
AB total time [1.2, 1.5], winter time [1.1, 1.4].

Points / Period	WECs									
	Oceantec		Pelamis		Pontoon Power C		Seabased AB		Wave Dragon	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
P7	3.48	1.94	4.13	2.93	7.83	4.95	0.09	0.06	72.01	53.27
P9	3.38	1.89	4.00	2.82	7.56	4.26	0.09	0.06	69.42	51.15
P10	3.29	1.85	4.03	2.84	7.66	4.80	0.09	0.06	73.05	53.77
P12	3.32	1.92	4.05	2.87	7.69	4.84	0.09	0.06	72.25	52.95
P14	3.37	1.97	3.98	2.80	7.66	4.83	0.09	0.06	70.26	51.00
P15	3.36	1.98	3.98	2.80	7.72	4.86	0.09	0.06	70.96	51.44

3. Wave energy in Archipelagos

Wave energy in the Canary Islands

- A 17th year period is studied (1996-2012), and for the more relevant points a bivariate distribution was designed.
  - The data was processed to get the maximum and the average values.
- Because in winter time the wave climate is more consistent, it is studied separated, corresponding this period of winter time to the months from October to March, included.
- According to the table seen, the points chosen for study are:



Wave energy in the Canary Islands

Wave data parameters

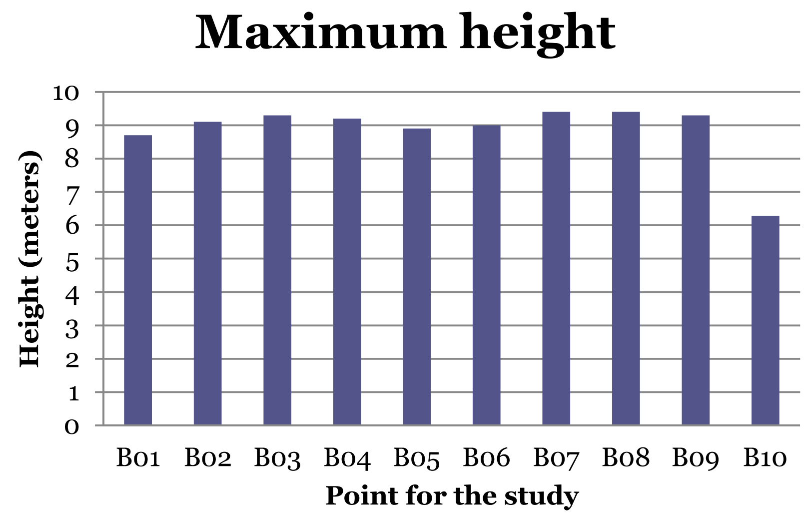
- Average values for the main wave parameters in the reference points for winter time for the 17th years period (1996 – 2012)

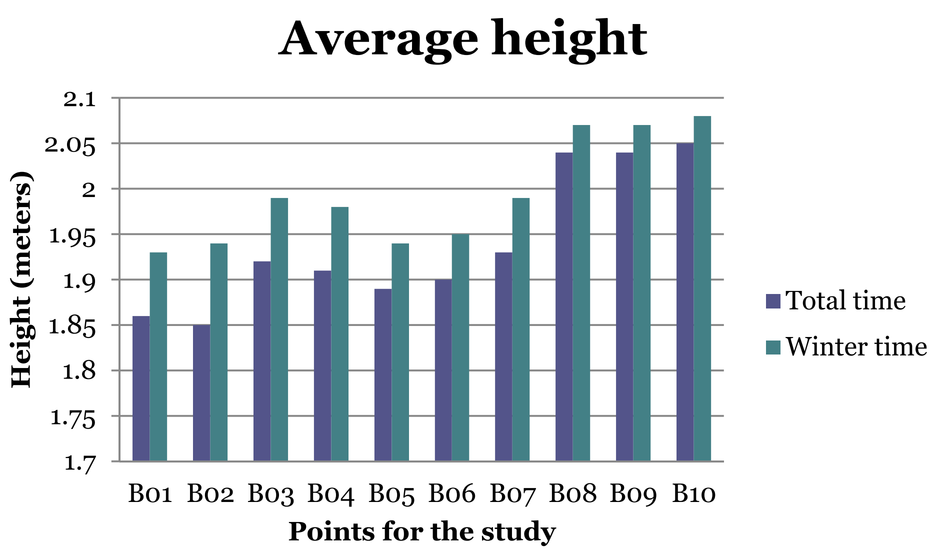
Point	Hs ave (m)	Te ave (s)	Tp ave (s)	Pw ave (kW/m)
B01	1.93	9.92	11.02	18.16
B02	1.94	9.96	11.07	18.43
B03	1.99	9.87	10.97	19.22
B04	1.98	9.88	10.98	19.02
B05	1.94	9.89	10.99	18.30
B06	1.95	9.88	10.98	18.47
B07	1.99	9.86	10.95	19.19
B08	2.07	9.76	10.84	20.55
B09	2.07	9.76	10.84	20.55
B10	2.08	9.75	10.83	20.73

Wave energy in the Canary Islands

Wave data parameters

- Maximum wave height in the reference points for total time for the 17th years period





- Average wave height in the reference points for total and winter time for the 17th years period

Wave energy in the Canary Islands

$$P_E = \frac{1}{100}\sum_{i=1}^{N1}\sum_{j=1}^{N2} p_{ij} \cdot P_{ij}$$

- The normalized electric power is calculated as:

$$P_{En} = \left(\frac{P_E}{P_{ET\,\max}}\right)$$

  - P_E is the estimated electric power in each location for the device considered for the 17 years period.
  - P_{ETmax} is the maximum value from all the geographical locations estimated for total time for the same device.
- Advantages of normalizing data:
  - Helps to compare the electric power since all the values of the different devices are expressed in the same range.
  - Provide an idea of the geographical variations of the estimated electrical power for each device.
  - Such approach provide an effective framework for estimating the efficiency of the WEC device in various geographical spaced.

Wave energy in the Canary Islands

- Average electric power in kW for the ten reference points with the six different WEC devices.

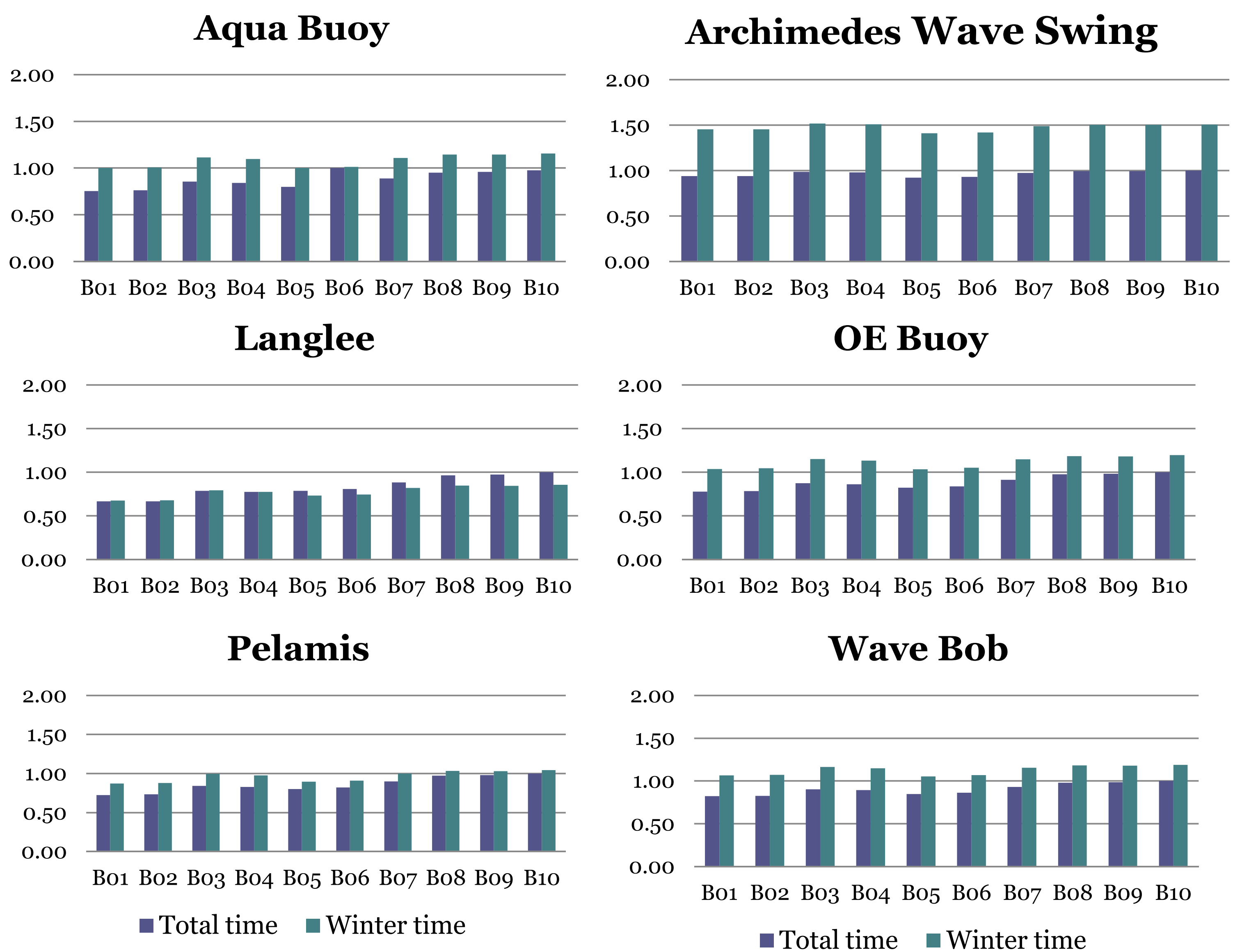
Points	Aqua Buoy		Archimedes Wave Swing		Langlee		OE Buoy		Pelamis		Wave Bob	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
B01	24,3	32,3	260,1	403,2	52,2	52,9	126,9	169,8	65,4	78,8	86,9	112,8
B02	24,6	32,5	260,2	403,0	52,1	53,0	128,2	171,2	66,2	79,5	87,4	113,4
B03	27,6	36,0	273,5	421,0	61,5	62,0	143,1	188,5	76,0	90,0	95,5	123,0
B04	27,2	35,4	271,8	418,5	60,5	60,6	141,1	185,5	74,8	88,3	94,4	121,3
B05	25,8	32,3	255,3	391,1	61,5	57,2	134,4	169,2	72,5	80,8	89,7	111,5
B06	32,3	32,7	257,7	394,0	63,1	58,2	137,1	171,8	74,1	82,1	91,3	112,9
B07	28,7	35,8	270,0	412,6	69,2	64,2	149,5	187,9	81,3	90,4	98,3	121,9
B08	30,7	37,0	275,6	417,1	75,6	66,3	159,6	193,7	87,8	93,4	103,7	124,9
B09	31,0	37,0	275,8	416,6	76,3	66,1	160,7	193,4	88,5	93,2	104,2	124,7
B10	31,5	37,3	277,4	418,1	78,3	67,1	163,6	195,5	90,3	94,2	105,7	125,7

- Normalized electric power in kW for the ten reference points with the six different WEC devices.

Points	Aqua Buoy		Archimedes Wave Swing		Langlee		OE Buoy		Pelamis		Wave Bob	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
B01	0,75	1,00	0,94	1,45	0,67	0,68	0,78	1,04	0,72	0,87	0,82	1,07
B02	0,76	1,01	0,94	1,45	0,67	0,68	0,78	1,05	0,73	0,88	0,83	1,07
B03	0,85	1,11	0,99	1,52	0,79	0,79	0,87	1,15	0,84	1,00	0,90	1,16
B04	0,84	1,10	0,98	1,51	0,77	0,77	0,86	1,13	0,83	0,98	0,89	1,15
B05	0,80	1,00	0,92	1,41	0,79	0,73	0,82	1,03	0,80	0,89	0,85	1,05
B06	1,00	1,01	0,93	1,42	0,81	0,74	0,84	1,05	0,82	0,91	0,86	1,07
B07	0,89	1,11	0,97	1,49	0,88	0,82	0,91	1,15	0,90	1,00	0,93	1,15
B08	0,95	1,15	0,99	1,50	0,97	0,85	0,98	1,18	0,97	1,03	0,98	1,18
B09	0,96	1,15	0,99	1,50	0,97	0,84	0,98	1,18	0,98	1,03	0,99	1,18
B10	0,98	1,15	1,00	1,51	1,00	0,86	1,00	1,19	1,00	1,04	1,00	1,19

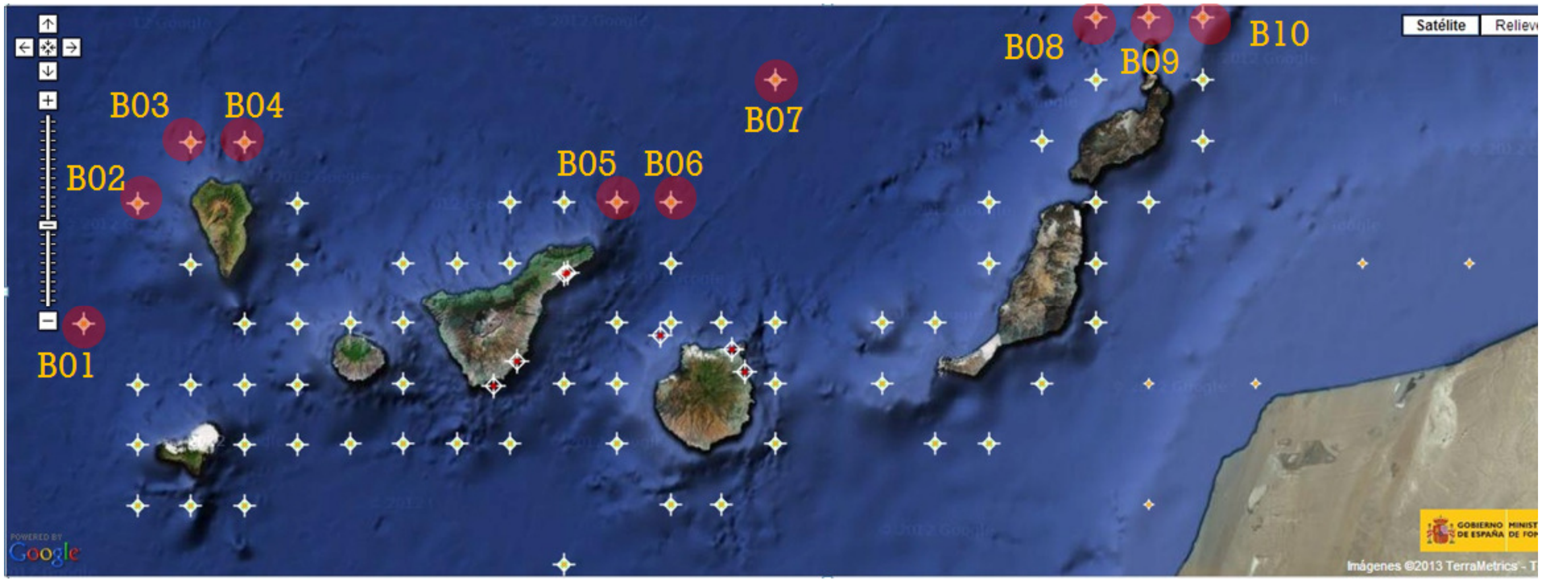
Wave energy in the Canary Islands

Normalized electric power for the six different devices in the reference points.

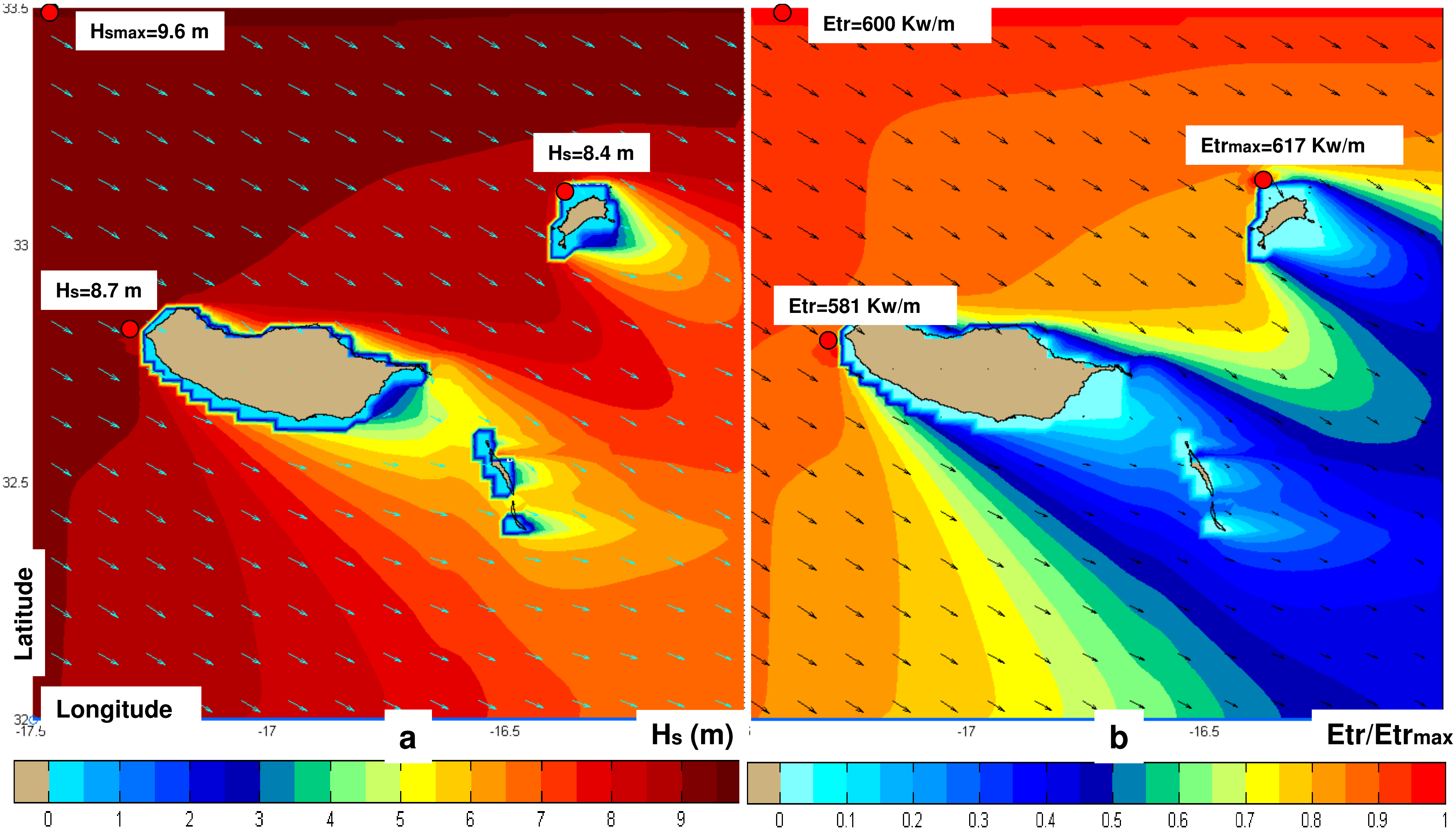


Wave energy in the Canary Islands

- The most energetic area of the archipelago
  - In general, the north of the Lanzarote island (B08, B09 and B10)
    - The point B10 being in fact the most energetic
  - In some cases, the area of the north of La Palma Island (B03 and B04)

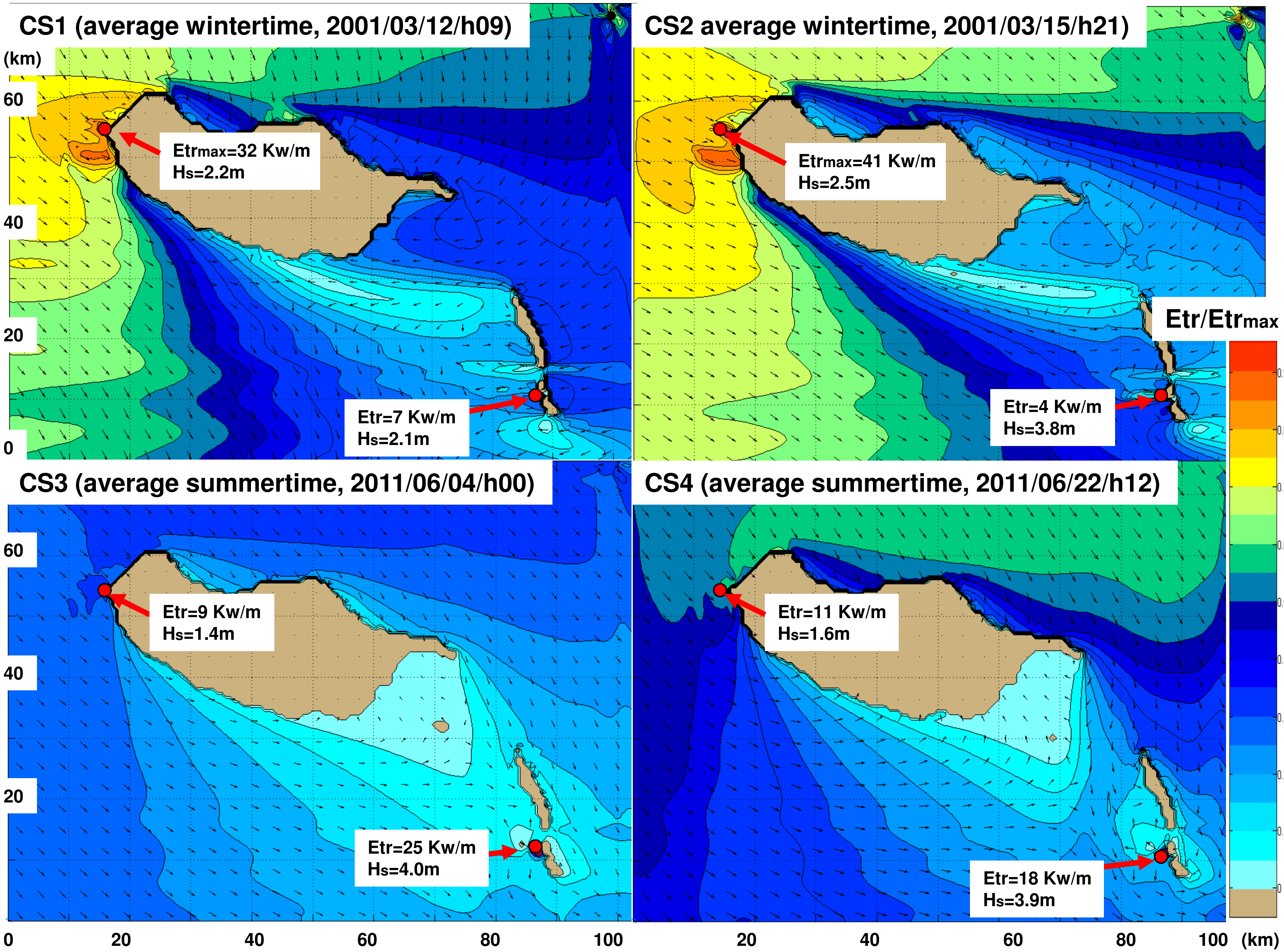


- The greatest variation between total time and winter time
  - Occurs at the AWS device.
- An atypical behavior
  - Langlee devices provides in general higher expected average electric power in the total time than in the winter time.

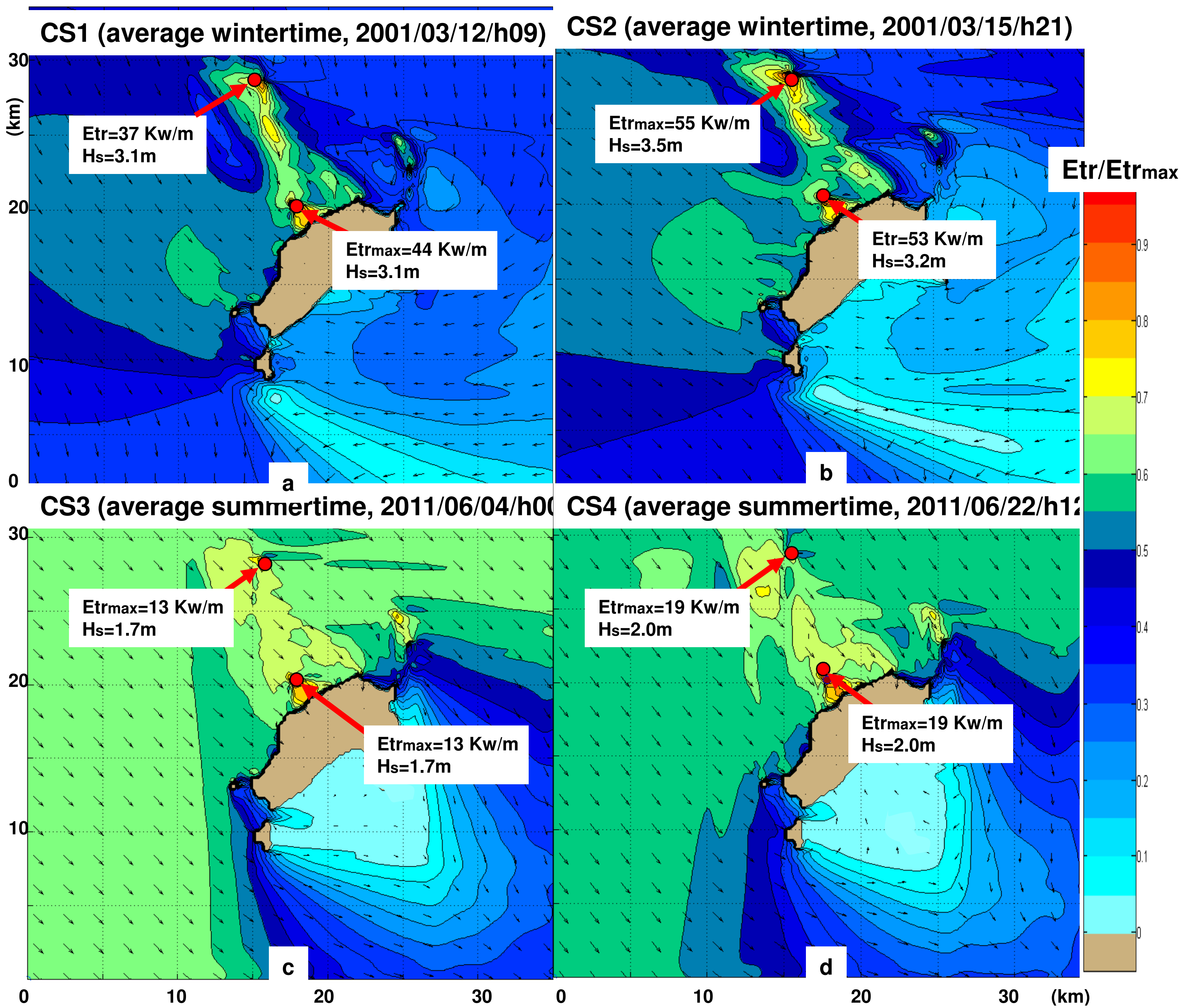


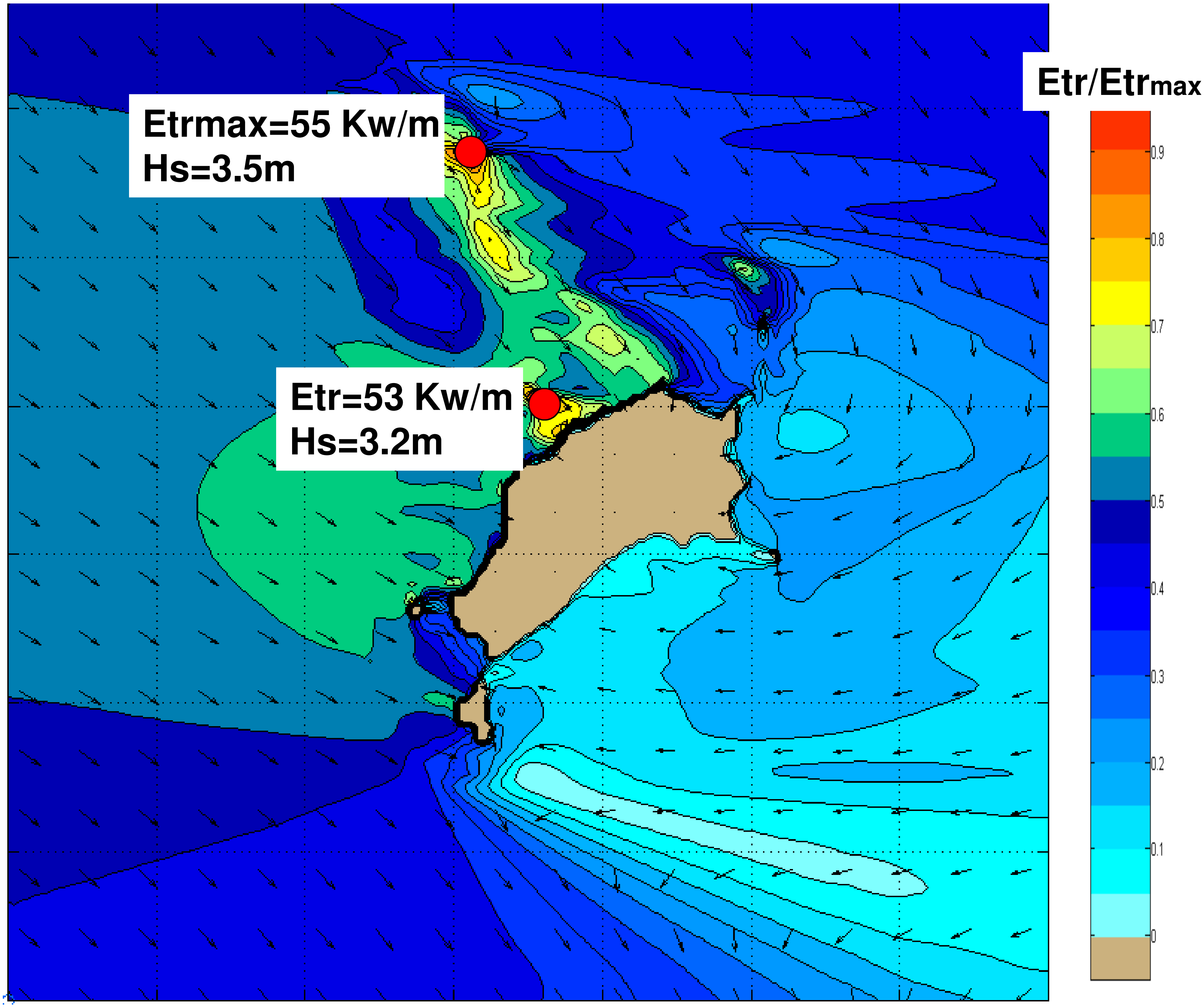
MADEIRA

Extreme energetic conditions in Madeira Archipelago, time frame 1997/12/18/h12 the large SWAN domain. a) H_s scalar fields and wave vectors; b) Normalized wave power field and energy transport vectors.

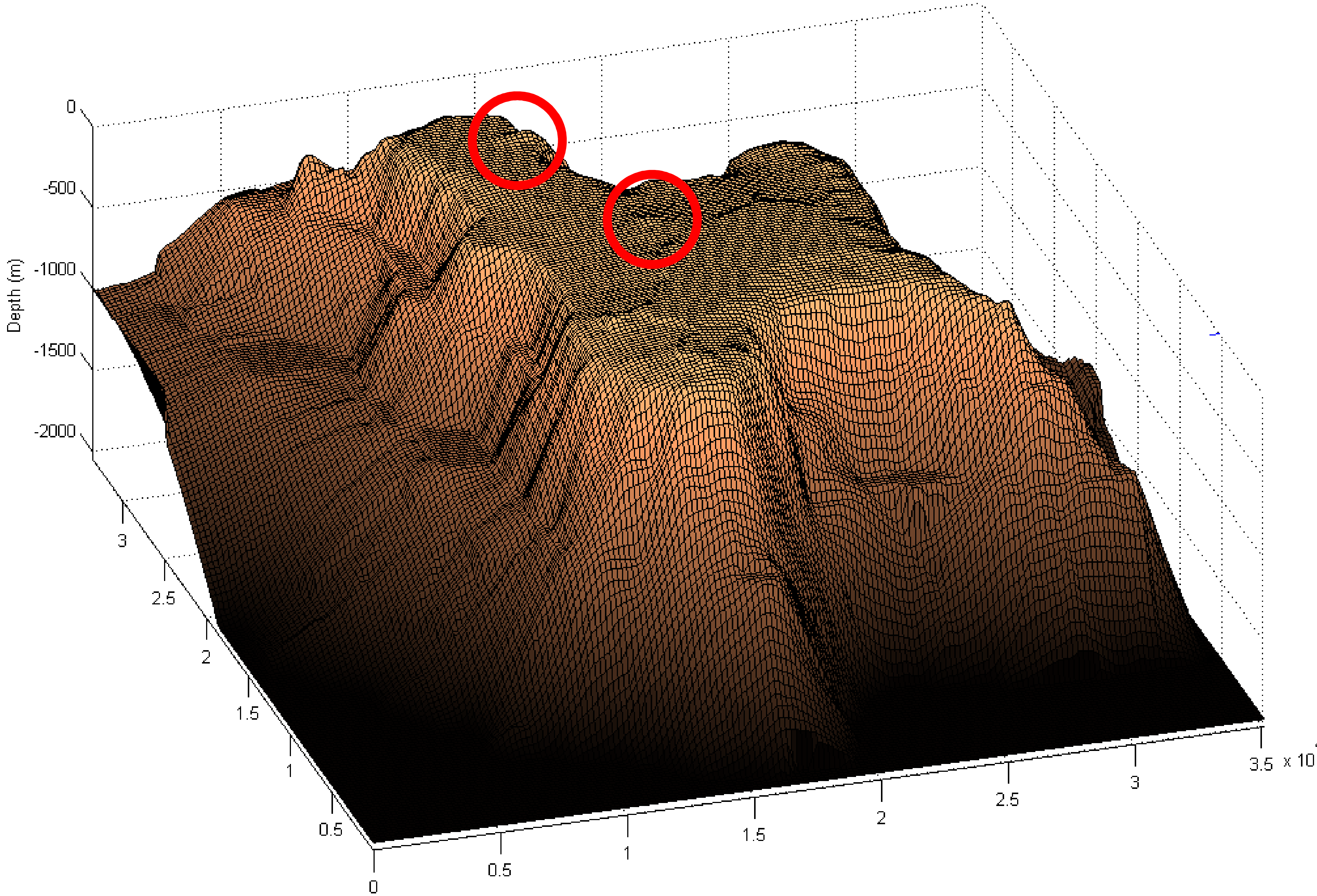


CS1 (average wintertime, 2001/03/12/h09)
CS2 average wintertime, 2001/03/15/h21)
CS3 (average summertime, 2011/06/04/h00)
CS4 (average summertime, 2011/06/22/h12)
(km)
60
40
20
0
Etrmax=32 Kw/m
Hs=2.2m
Etr=7 Kw/m
Hs=2.1m
Etrmax=41 Kw/m
Hs=2.5m
Etr=4 Kw/m
Hs=3.8m
Etr=9 Kw/m
Hs=1.4m
Etr=25 Kw/m
Hs=4.0m
Etr=11 Kw/m
Hs=1.6m
Etr=18 Kw/m
Hs=3.9m
Etr/Etrmax
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
(km)

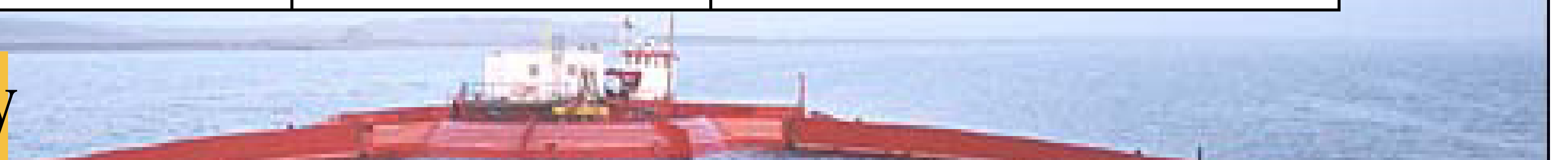

CS1 (average wintertime, 2001/03/12/h09)
Etr=37 Kw/m
Hs=3.1m
Etrmax=44 Kw/m
Hs=3.1m
a
CS2 (average wintertime, 2001/03/15/h21)
Etrmax=55 Kw/m
Hs=3.5m
Etr=53 Kw/m
Hs=3.2m
b
CS3 (average summertime, 2011/06/04/h00
Etrmax=13 Kw/m
Hs=1.7m
Etrmax=13 Kw/m
Hs=1.7m
c
CS4 (average summertime, 2011/06/22/h12
Etrmax=19 Kw/m
Hs=2.0m
Etrmax=19 Kw/m
Hs=2.0m
d
Etr/Etrmax
(km)
(km)



Etrmax=55 Kw/m
Hs=3.5m
Etr=53 Kw/m
Hs=3.2m
Etr/Etrmax
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


0
-500
-1000
-1500
-2000
Depth (m)
3
2.5
2
1.5
1
0.5
0
0.5
1
1.5
2
2.5
3
3.5
x 10^4

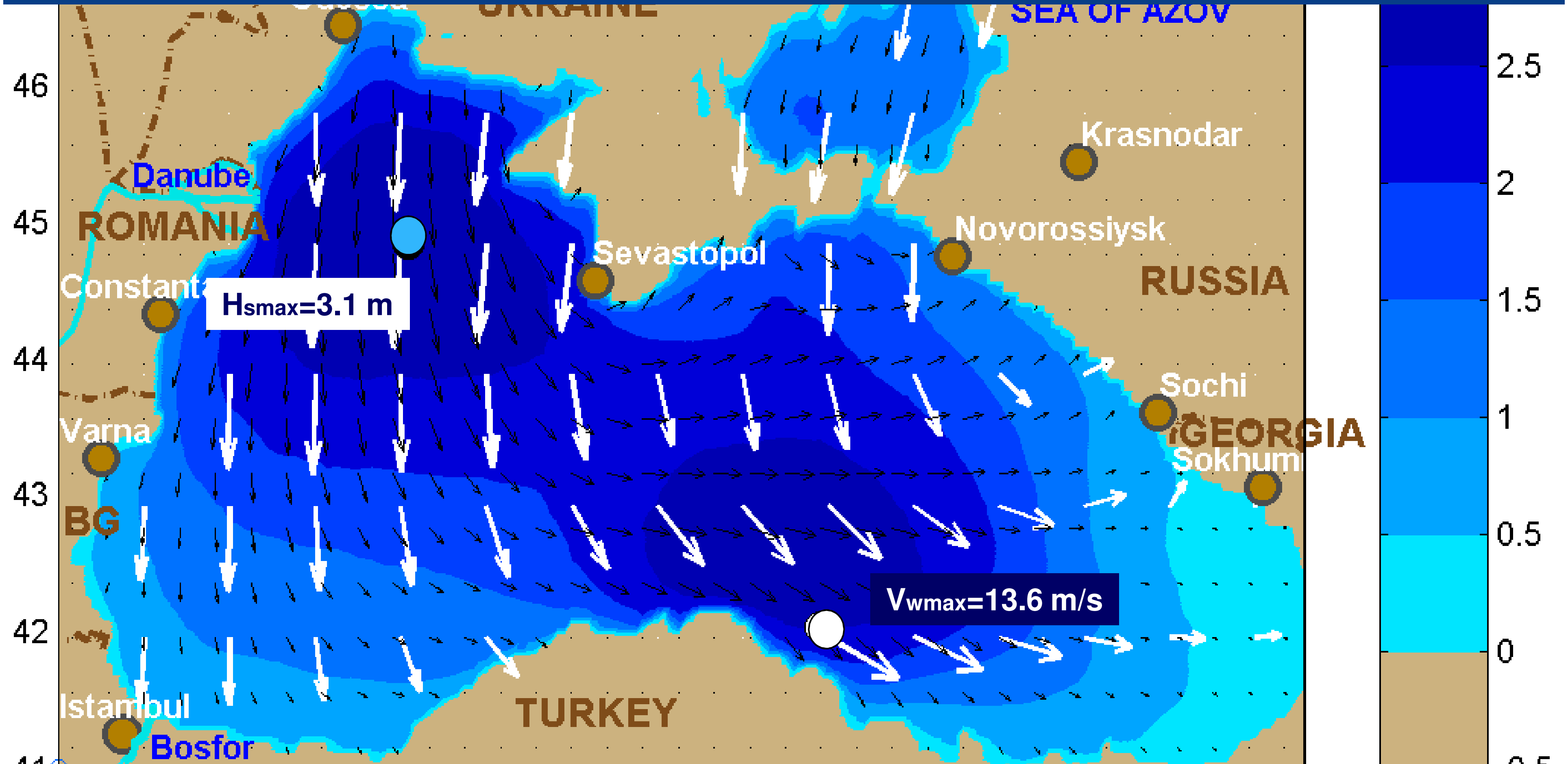
Point	WAVE DRAGON	PELAMIS	AQUA BUOY
MA1	1	9	29
PS2	1	16	33



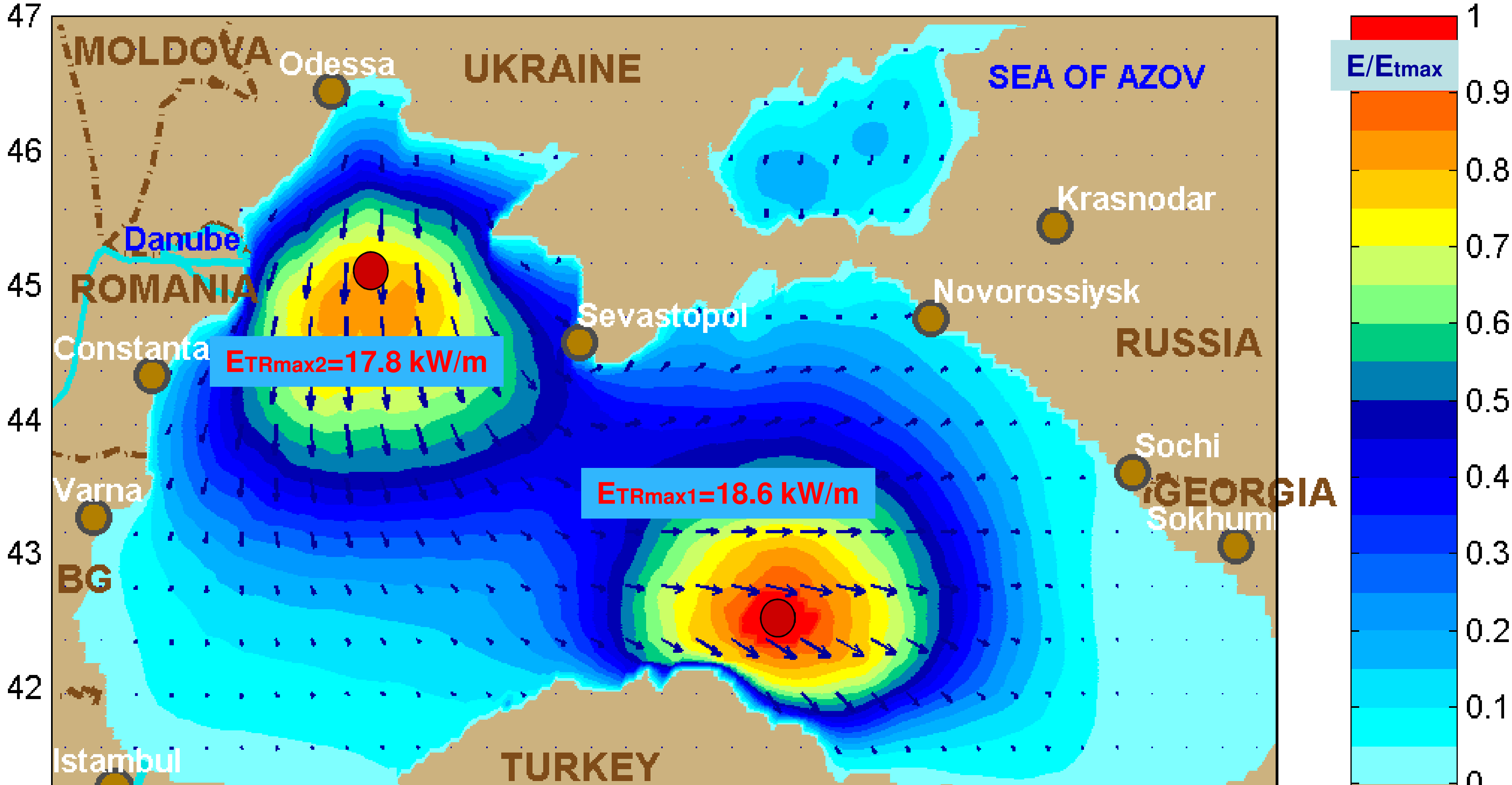
$I_{wet}=P_E/P_W$

Point		PELAMIS	W. DRAGON	AQUA BUOY
MA1	P_E (kw)	134.9	1147.4	40.2
Pw=51	I_{WET}	2.62	22.28	0.78
PS2	P_E (kw)	105.3	1644.2	50.4
Pw=65	I_{WET}	1.61	25.14	0.77

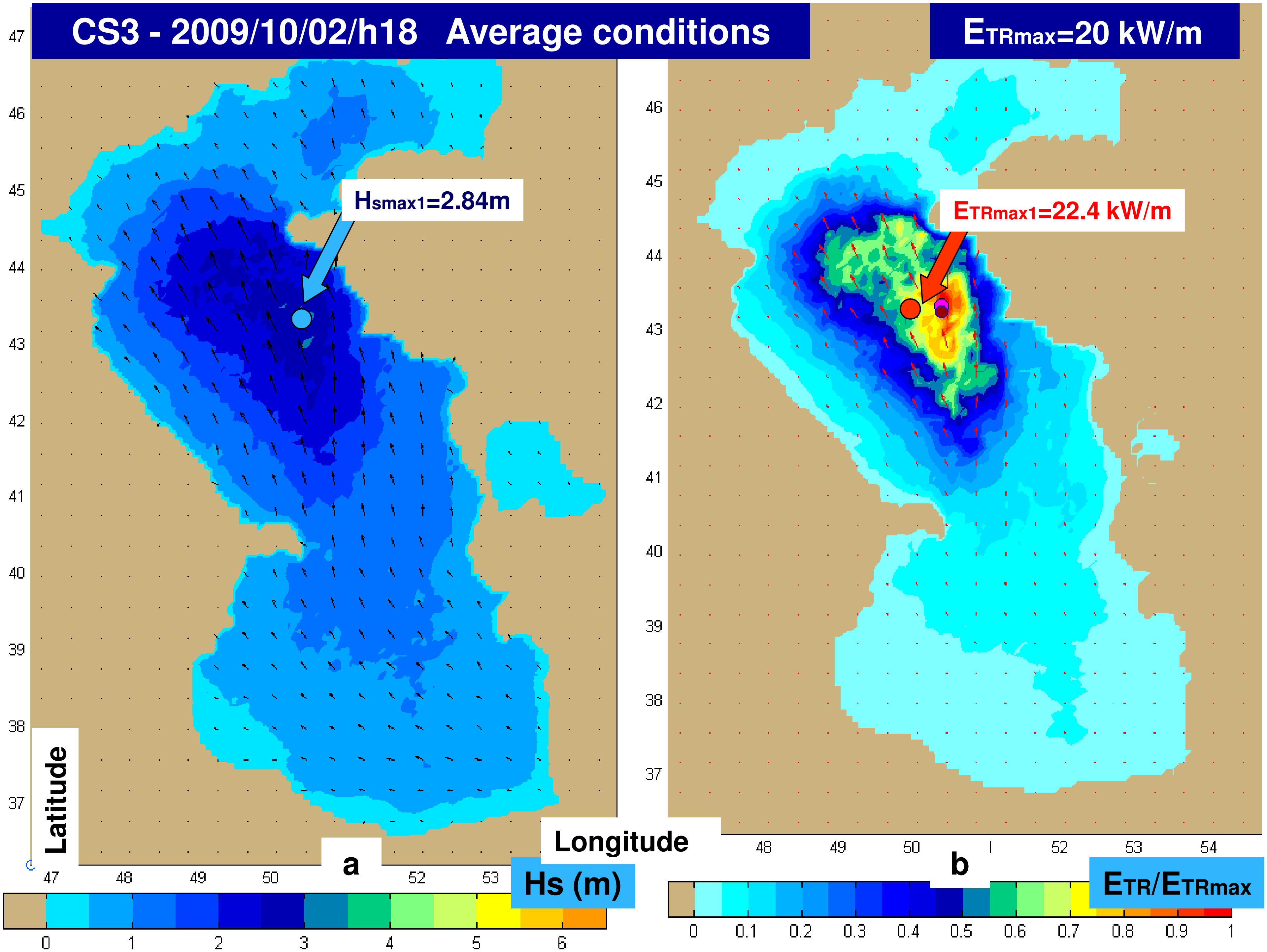
4. Wave energy in enclosed seas



Case study 1 - 1997/01/12/h12, average energetic situation. In background significant wave height scalar fields, in foreground wave vectors (black arrows) and wind vectors (white arrows);



Case study 1 - 1997/01/12/h12, average energetic situation. In background normalized wave power, in foreground energy transport vectors (in kW/m of wave front).



CS3 - 2009/10/02/h18 Average conditions
ETRmax=20 kW/m
Hsmax1=2.84m
ETRmax1=22.4 kW/m
Latitude
Longitude
a
b
Hs (m)
ETR/ETRmax
0
1
2
3
4
5
6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Wave energy in the Romanian nearshore of the Black Sea

Average expected electric power (kW) for the systems **AquaBuoy**, **Pelamis** & **Wave Dragon for the locations** Gloria (in the Black Sea) and FINO1 (in the North Sea). Results reported for total and winter time, respectively.

Sistem WEC → / Perioadă ↓	AquaBuoy	Pelamis	Wave Dragon
Gloria (Marea Neagră)			
Total	15.87	59.71	391.20
Sezon de iarnă	23.93	88.97	578.11
FINO 1 (Marea Nordului)			
Total	12.08	69.70	735.43
Sezon de iarnă	25.48	98.04	895.07

Nominal power (250kW-AquaBuoy, 750kW-Pelamis şi 7000kW-Wave Dragon)

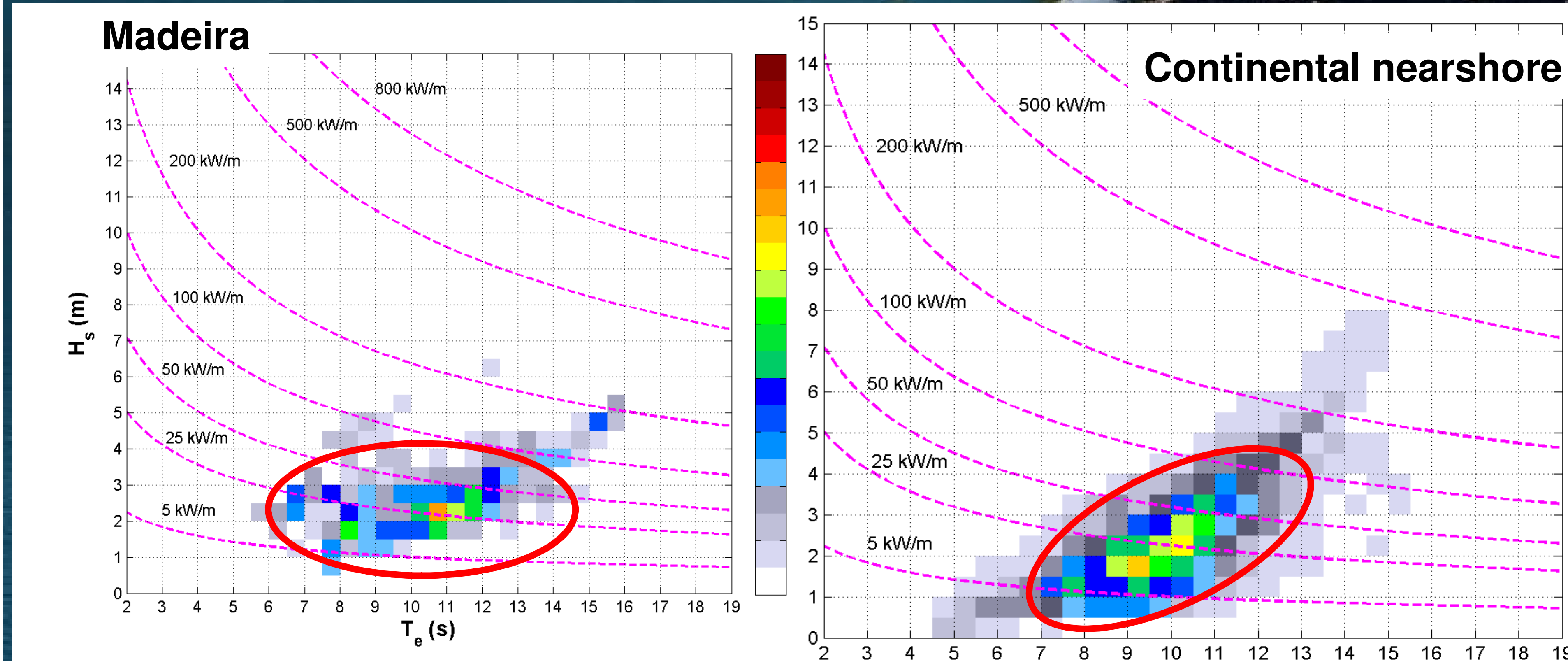
Load factor (%) winter time

- **Gloria →** **Pelamis**: 11.9%, **AquaBuoy**: 9.5%, **Wave Dragon**: 8.2% .
- **FINO1 →** **Pelamis**:13.07%, **AquaBuoy**: 8.4%, **Wave Dragon**:12.78%.

5. Discussions and conclusions

- When installing a wave farm composed of a large WEC array the analysis of the wave climate from the perspective of the distribution of the wave energy along the sea states represents a fundamental issue for obtaining a higher efficiency.
- From the comparisons performed with the results from the archipelagos it appears that the efficiency of the wave farms in island environments is expected to be lower than close to the continental coasts, although the expected wave energy might be higher close to the islands. This is because in the island environment the wave energy is usually more scattered than close to the continental coasts.

5. Discussions and conclusions



- **The present work provides valuable information related to the effectiveness of various technologies for the wave energy extraction that would operate in various coastal environments. Moreover, the results can be easily extrapolated to some other coastal environments.**

Average electric power expected

Northwest of Spain

Points / Period	Oceantec TT	Oceantec WT	Pelamis TT	Pelamis WT	Pontoon Power C TT	Pontoon Power C WT	Seabased AB TT	Seabased AB WT	Wave Dragon TT	Wave Dragon WT
P7	104.98	103.59	124.47	155.92	236.27	263.67	2.79	3.31	2172.40	2839.50
P9	107.14	106.50	126.59	158.60	239.39	239.36	2.84	3.38	2197.80	2875.00
P10	94.40	94.38	115.57	144.76	219.75	244.45	2.65	3.17	2095.20	2736.40
P12	97.20	100.43	118.37	149.97	224.85	253.12	2.69	3.24	2112.60	2768.60
P14	99.87	105.39	118.06	150.20	227.25	258.50	2.71	3.28	2083.80	2730.90
P15	96.52	102.79	114.24	145.40	221.50	252.10	2.65	3.22	2037.20	2667.60

Portugal continetal

P_E (kW) WD total time [767, 956], winter time [1153,1436],
AWS total time [247, 287], winter time [396, 455],
PEL total time [79, 102] , winter time [109, 142],
AB total time [29, 36], winter time [41, 52].

PE (kW)

WD total time [767, 956], winter time [1153,1436],
AWS total time [247, 287], winter time [396, 455],
PEL total time [79, 102] , winter time [109, 142],
AB total time [29, 36], winter time [41, 52].

Canary islands

Points	Aqua Buoy		Archimedes Wave Swing		Langlee		OE Buoy		Pelamis		Wave Bob	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
B01	24,3	32,3	260,1	403,2	52,2	52,9	126,9	169,8	65,4	78,8	86,9	112,8
B02	24,6	32,5	260,2	403,0	52,1	53,0	128,2	171,2	66,2	79,5	87,4	113,4
B03	27,6	36,0	273,5	421,0	61,5	62,0	143,1	188,5	76,0	90,0	95,5	123,0
B04	27,2	35,4	271,8	418,5	60,5	60,6	141,1	185,5	74,8	88,3	94,4	121,3
B05	25,8	32,3	255,3	391,1	61,5	57,2	134,4	169,2	72,5	80,8	89,7	111,5
B06	32,3	32,7	257,7	394,0	63,1	58,2	137,1	171,8	74,1	82,1	91,3	112,9
B07	28,7	35,8	270,0	412,6	69,2	64,2	149,5	187,9	81,3	90,4	98,3	121,9
B08	30,7	37,0	275,6	417,1	75,6	66,3	159,6	193,7	87,8	93,4	103,7	124,9
B09	31,0	37,0	275,8	416,6	76,3	66,1	160,7	193,4	88,5	93,2	104,2	124,7
B10	31,5	37,3	277,4	418,1	78,3	67,1	163,6	195,5	90,3	94,2	105,7	125,7

Madeira archipelago

Point	PELAMIS	W. DRAGON	AQUA BUOY
MA1	134.9	1147.4	40.2
PS2	105.3	1644.2	50.4

P_E (kW)

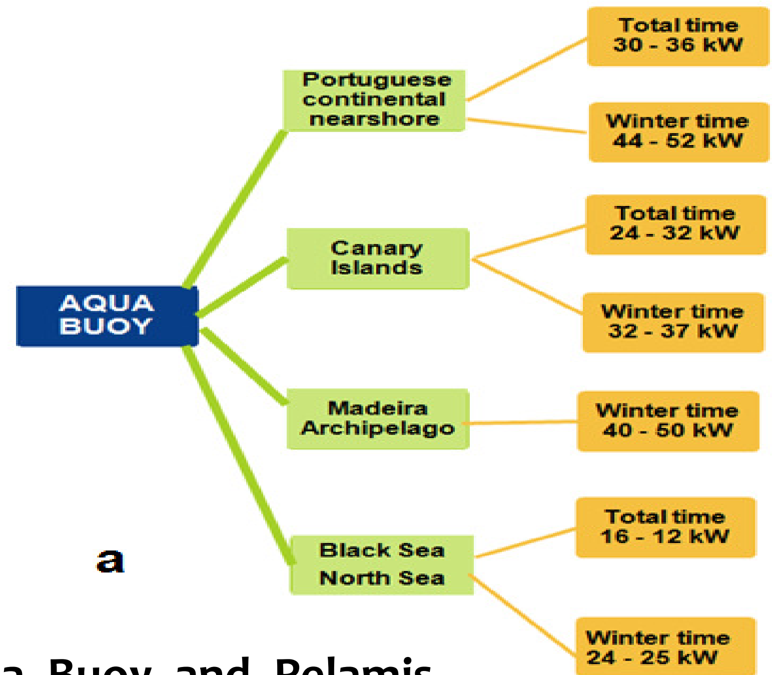
WD total time [767, 956], winter time [1153,1436],
AWS total time [247, 287], winter time [396, 455],
PEL total time [79, 102] , winter time [109, 142],
AB total time [29, 36], winter time [41, 52].

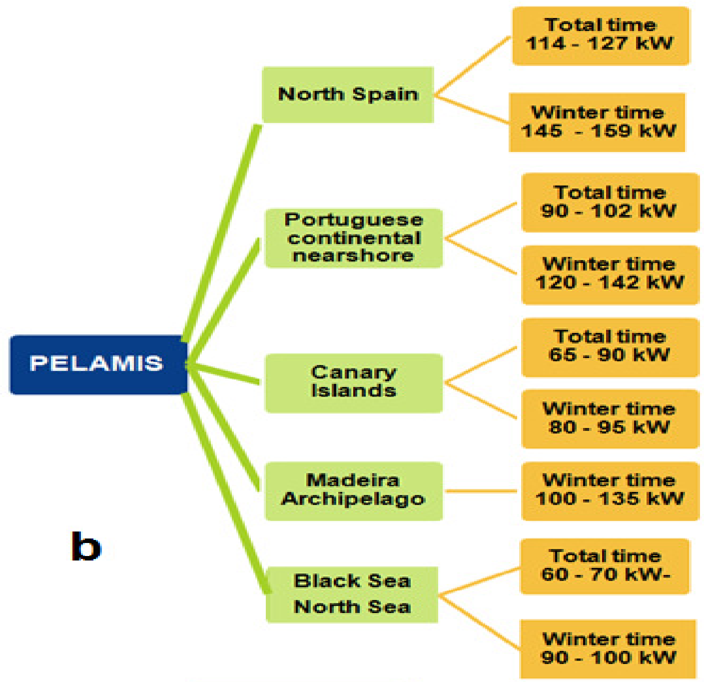
Canary islands

Points	Aqua Buoy		Archimedes Wave Swing		Langlee		OE Buoy		Pelamis		Wave Bob	
	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT	TT	WT
B01	24,3	32,3	260,1	403,2	52,2	52,9	126,9	169,8	65,4	78,8	86,9	112,8
B02	24,6	32,5	260,2	403,0	52,1	53,0	128,2	171,2	66,2	79,5	87,4	113,4
B03	27,6	36,0	273,5	421,0	61,5	62,0	143,1	188,5	76,0	90,0	95,5	123,0
B04	27,2	35,4	271,8	418,5	60,5	60,6	141,1	185,5	74,8	88,3	94,4	121,3
B05	25,8	32,3	255,3	391,1	61,5	57,2	134,4	169,2	72,5	80,8	89,7	111,5
B06	32,3	32,7	257,7	394,0	63,1	58,2	137,1	171,8	74,1	82,1	91,3	112,9
B07	28,7	35,8	270,0	412,6	69,2	64,2	149,5	187,9	81,3	90,4	98,3	121,9
B08	30,7	37,0	275,6	417,1	75,6	66,3	159,6	193,7	87,8	93,4	103,7	124,9
B09	31,0	37,0	275,8	416,6	76,3	66,1	160,7	193,4	88,5	93,2	104,2	124,7
[illegible]	[illegible]	[illegible]	277,4	418,1	78,3	67,1	163,6	195,5	90,3	94,2	105,7	125,7

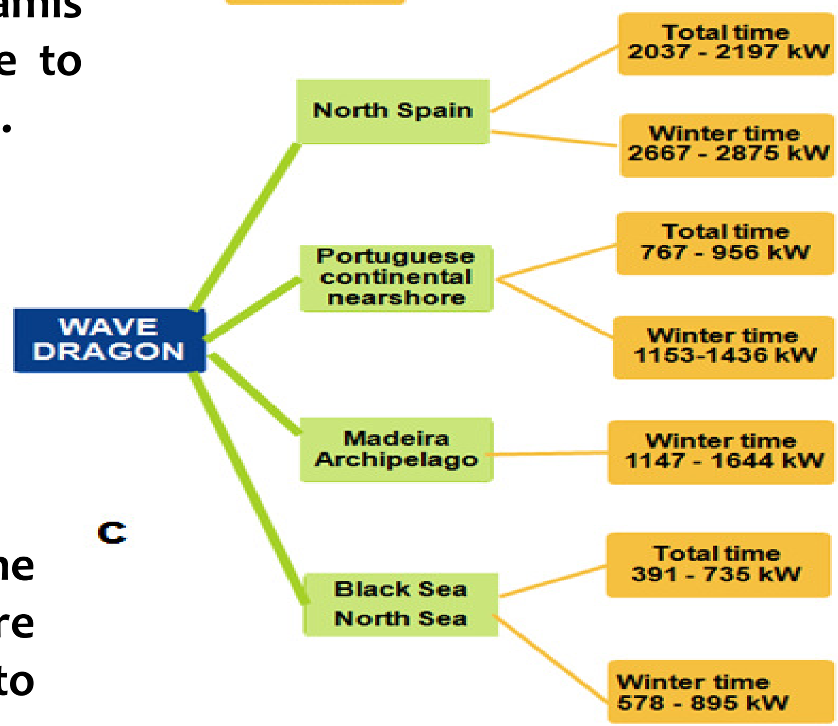
Sea environment

Sistem WEC → / Perioadă ↓	AquaBuoy	Pelamis	Wave Dragon
Gloria (Marea Neagră)			
Total	15.87	59.71	391.20
Sezon de iarnă	23.93	88.97	578.11
FINO 1 (Marea Nordului)			
Total	12.08	69.70	735.43
Sezon de iarnă	25.48	98.04	895.07





- Aqua Buoy and Pelamis perform better close to the continental coast.



- It is expected that the same features are characteristic also to the other WECs.

ACKNOWLEDGEMENT:

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Evaluation of the electric power expected from various wave energy converters operating in the coastal environment

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