



Wave modelling for the Wave Hub: Impacts of climate change

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and

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General Objectives

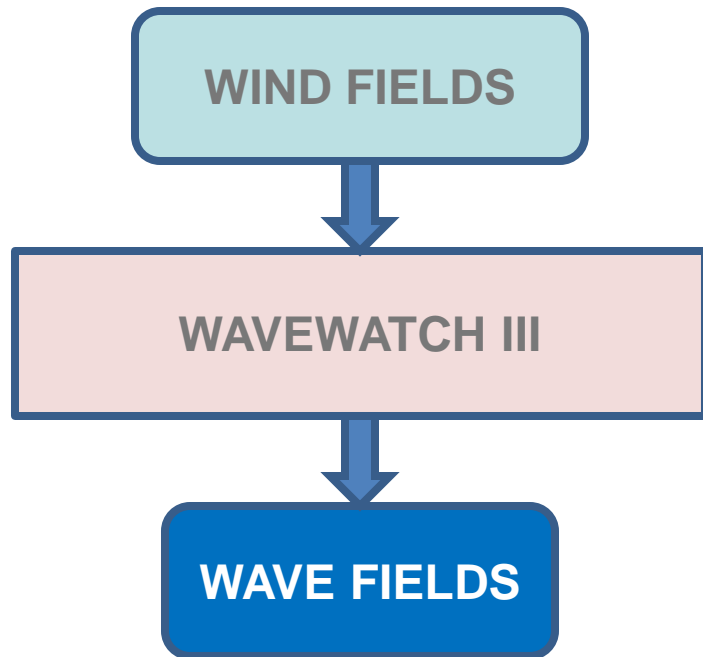
- What is the impact of climate change scenarios on the *wave energy resource* at Wave Hub?
- What is the statistical significance of such changes?

Focus on device developers/ operators:



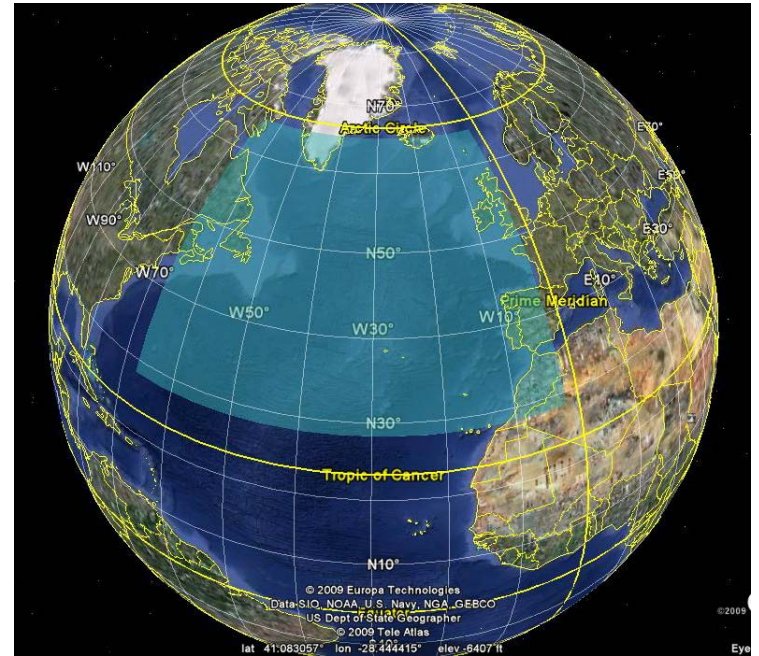
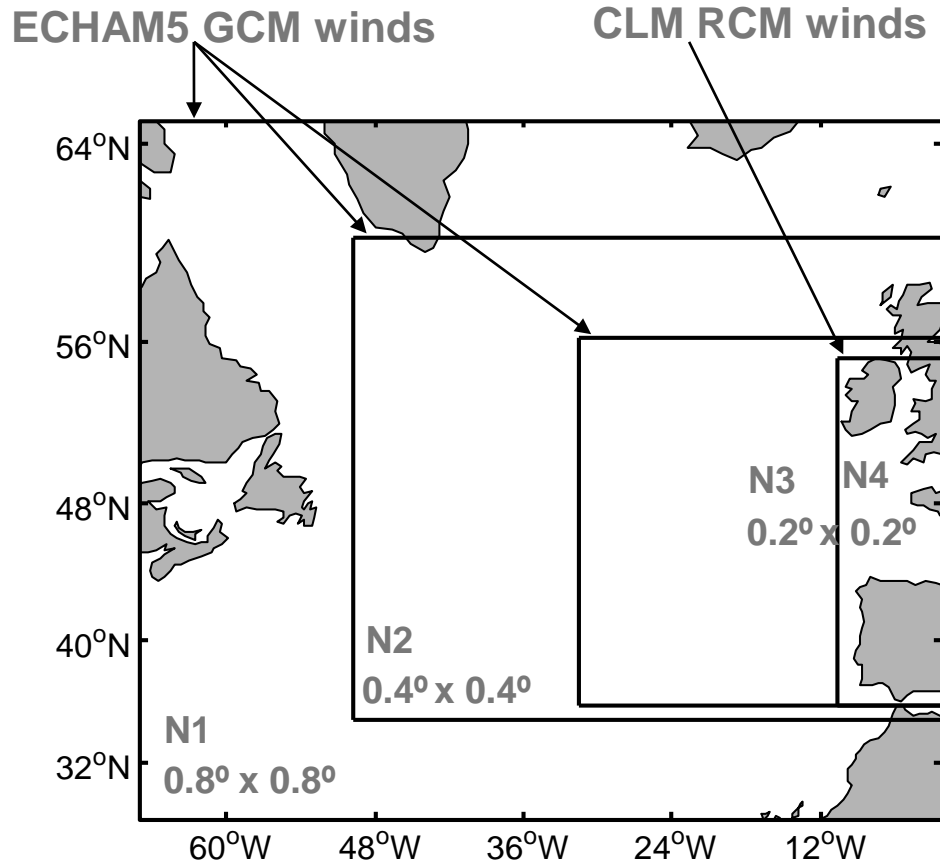
- Assessment of changes in:
 - Average power generation
 - Idle time
 - Downtime/Maintenance windows
- Impact on wave device design

Modelling Approach



- Comparison of “time-slices”
 - **present** (control): 1961-2000
vs
 - **future** (scenario): 2061-2100
- Winds: Climate Change Experiments (Max-Planck-Institute for Meteorology)
 - **ECHAM5** – Global Climate Model
 - **CLM** – Regional Climate Model
- IPCC Scenarios:
 - **B1** - low emissions
 - **A1B** - medium-high emissions
 - **A2** - high emissions

WW3 Model Set-up



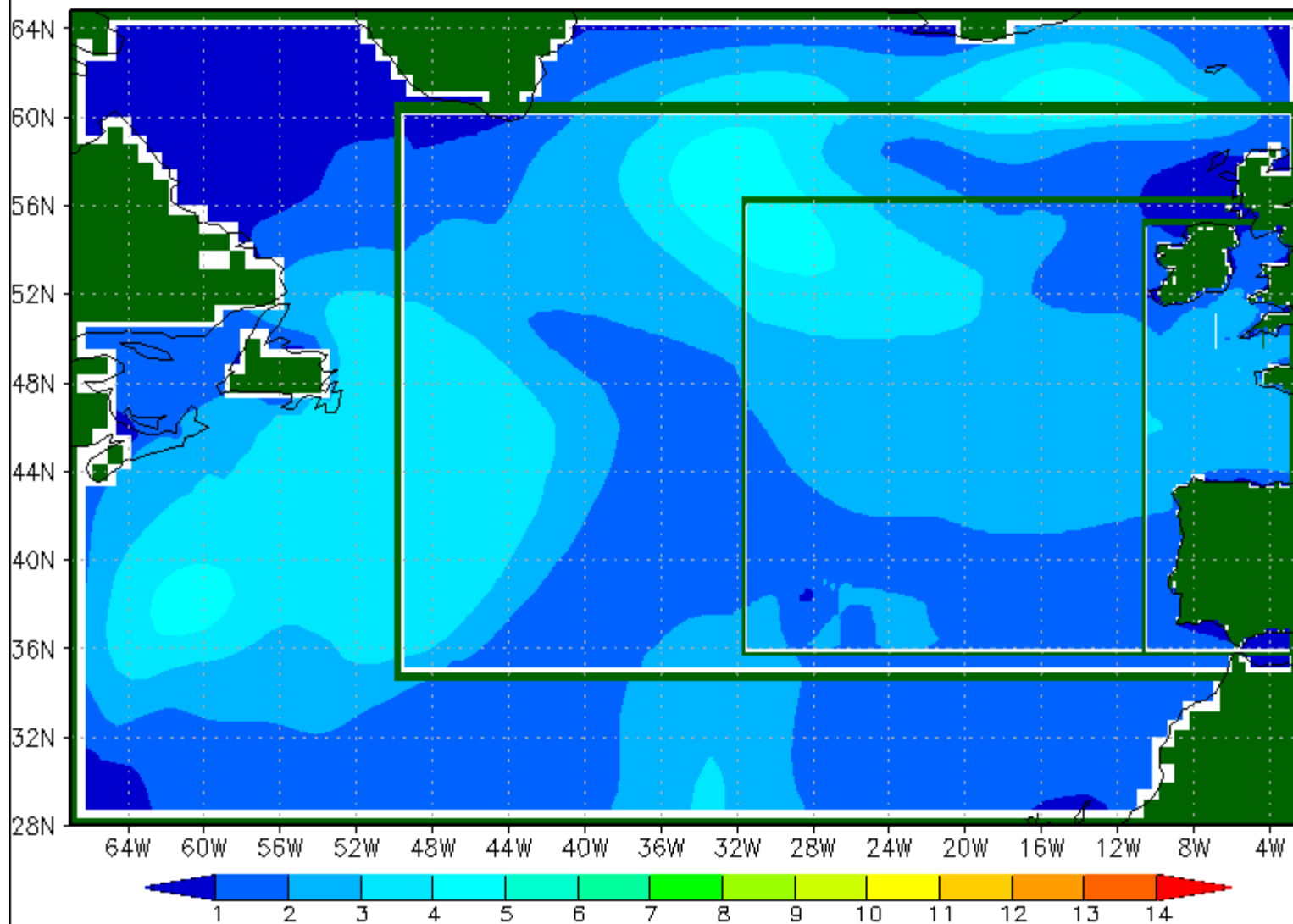
Bathymetry:
- ETOPO01 at ~0.016° (NGDC, 2008)

Wave hindcast from each wind forcing results in one time slice of a *wave climate*, i.e. a 40-year time-series of 3-hourly wave conditions (H_s , T_m , θ) at each grid point.

WW3 - Nests

Hs (shaded, m)

valid 1960/01/13 11:00z

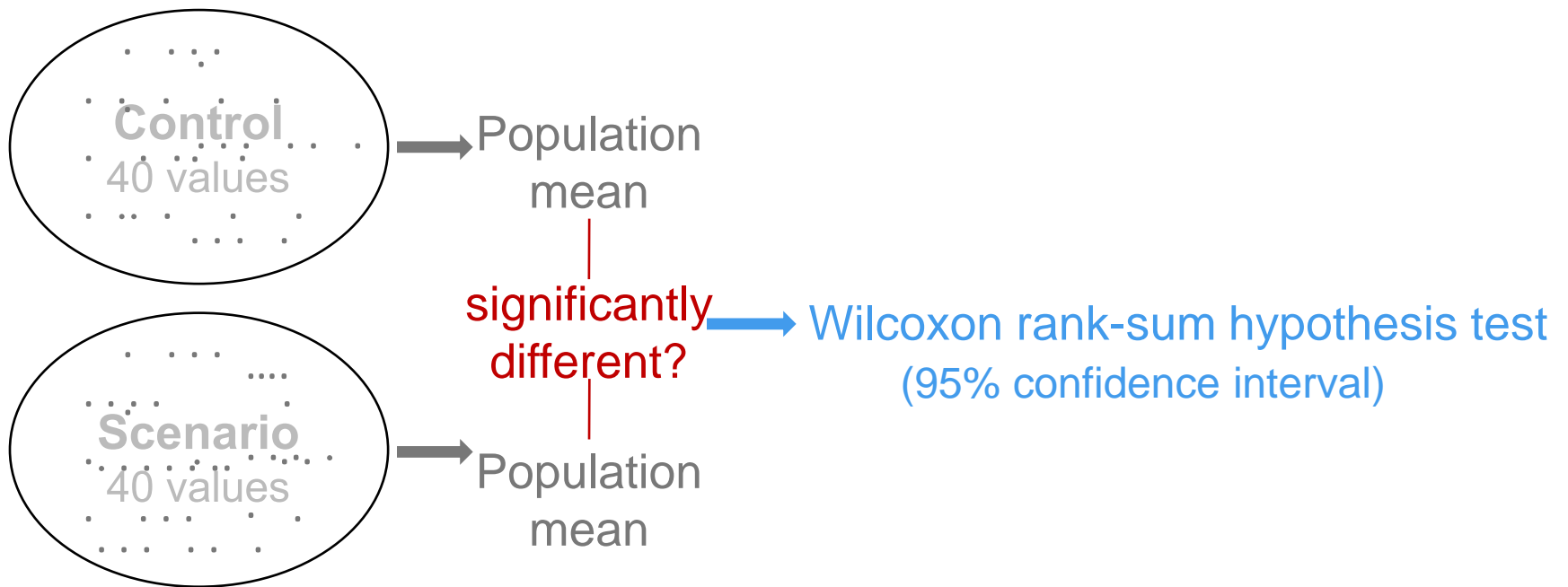


Statistical Analysis

Compare control and scenario with respect to:

- Field statistics – (every domain grid point)
 - mean H_s
 - 99-percentile of H_s
- Joint statistics – (only at Wave Hub)
 - discretised $H_s - T_m$ bins (for power matrix)
 - idle time
 - average power generation
 - downtime/ maintenance windows

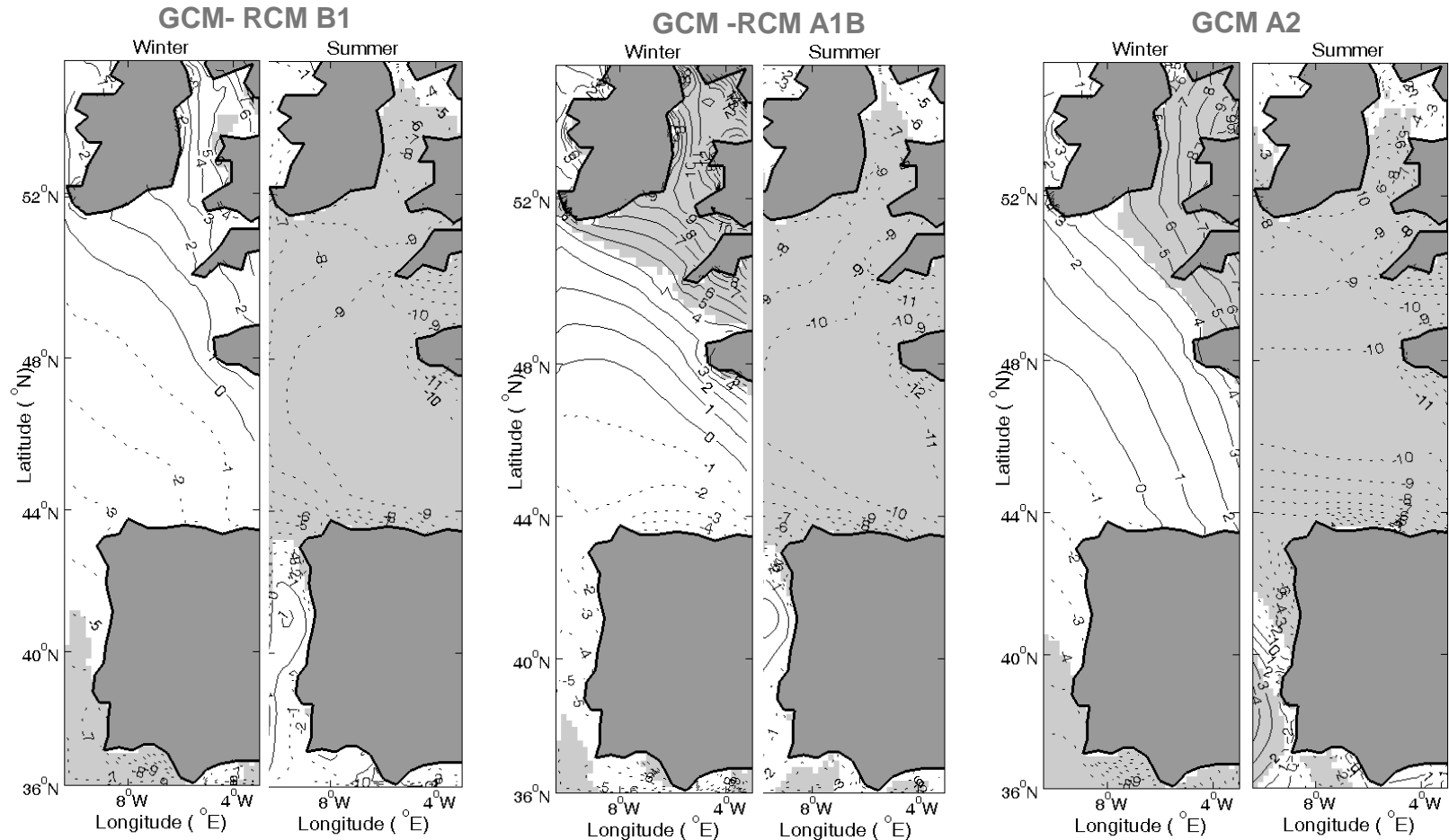
Statistical Analysis





Results

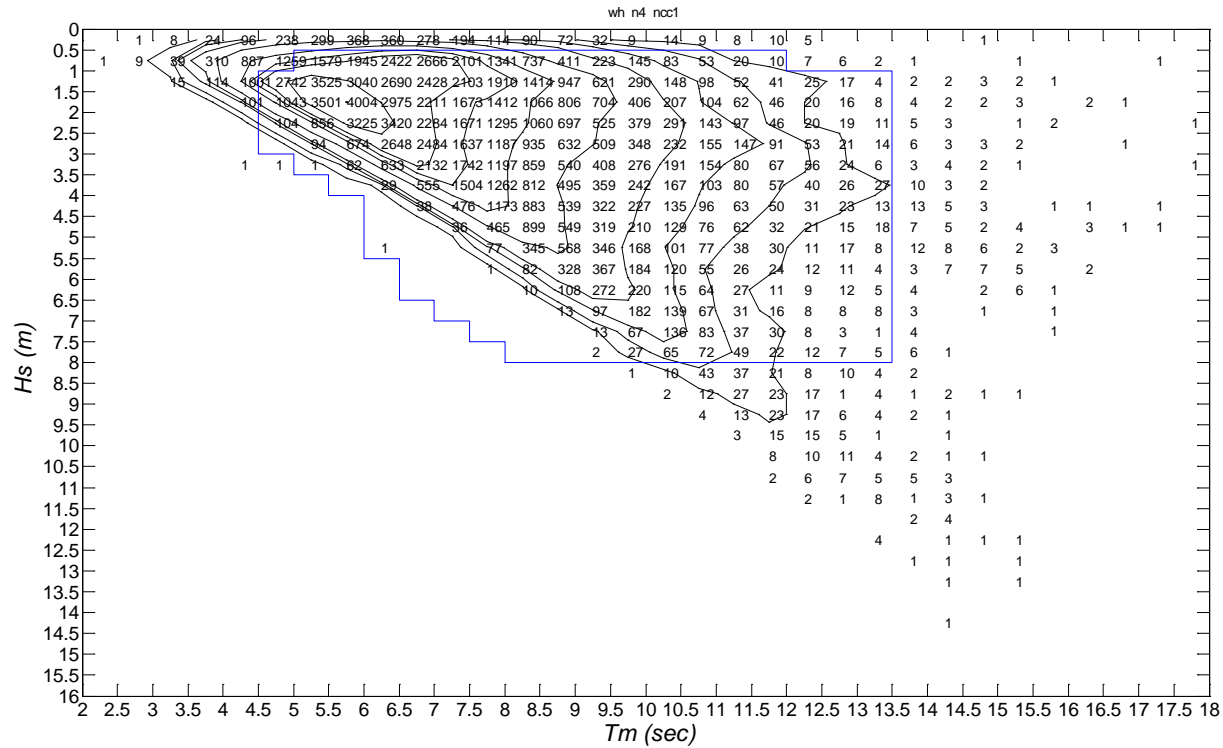
Mean Hs



- **Winter (Dec – Feb)** : increases over the Northern domain (up to 10%), decrease over the Southern (up to 5%)
- **Summer (Jun – Aug)** : general decrease (8-11%)

Hs-Tm Joint Distribution

What is the effect on wave device output?

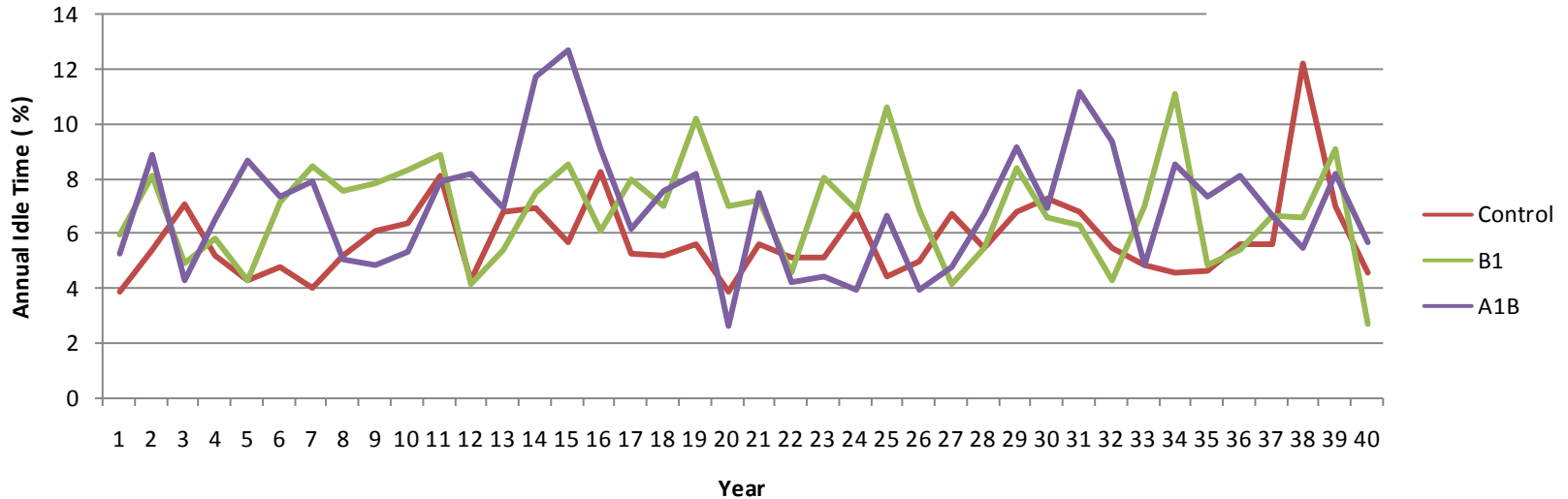


Pelamis power matrix →

Significant wave height ($H_{1/10}$, m)	Power period (T_{pow} , s)																
	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

Source: <http://www.pelamiswave.com>

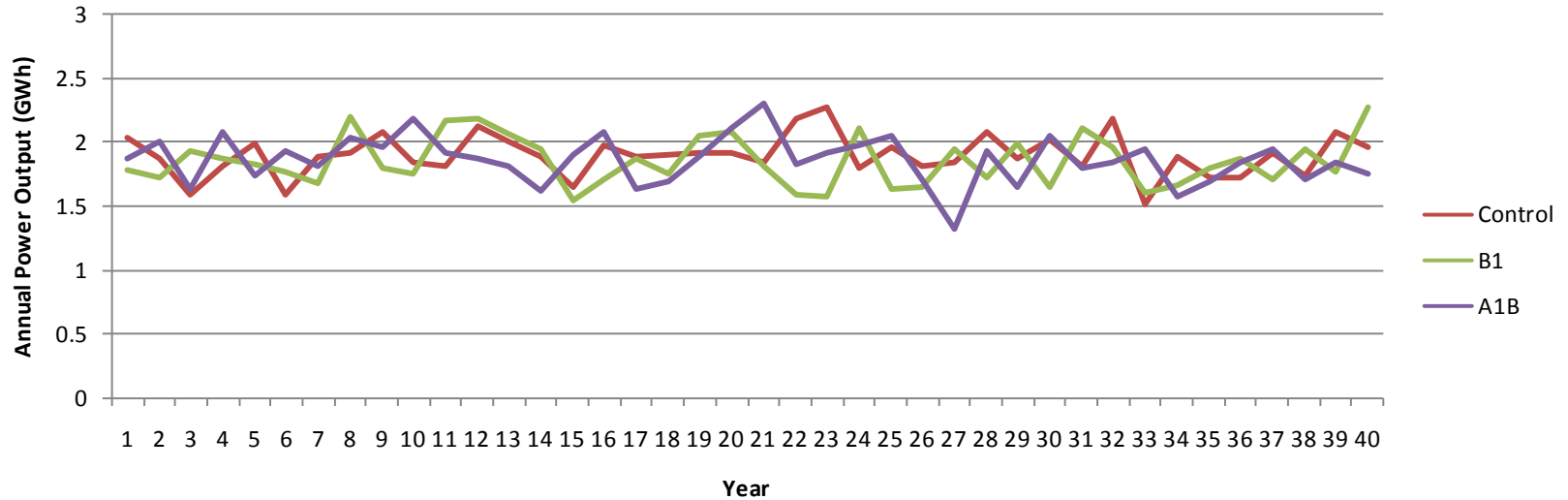
Idle Time



Changes in idle time

	Yearly (Jan – Dec)		Summer (Jun – Aug)		Winter (Dec– Feb)	
	Idle Time (%)	P-value	Idle Time (%)	P-value	Idle Time (%)	P-value
Control Average	5.80		9.46		3.52	
Mean Difference (B1 minus Control)	1.07	0.0029	2.47	0.0155	-0.22	0.6579
Mean Difference (A1B minus Control)	1.20	0.0078	1.78	0.2308	0.48	0.3334

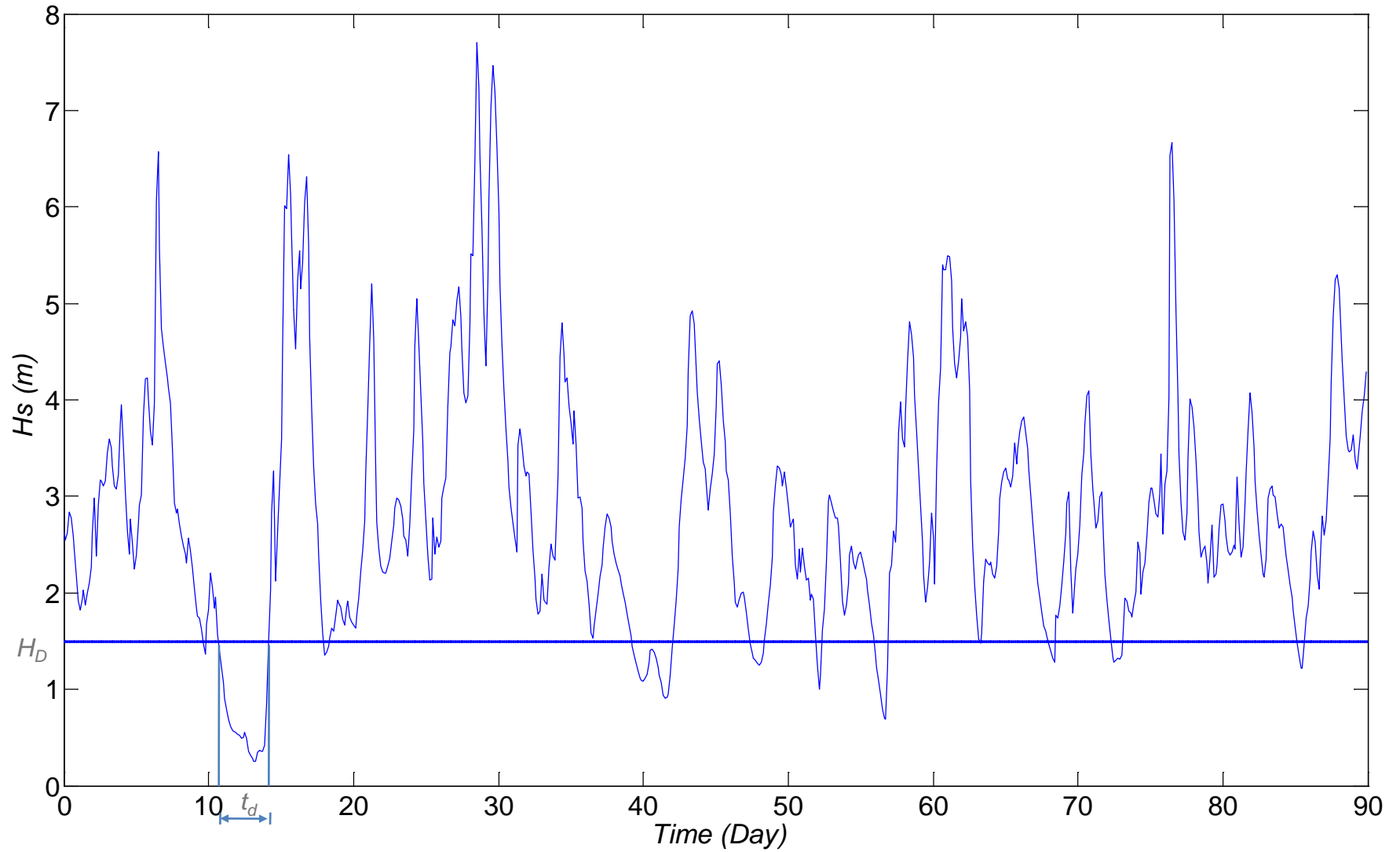
Average Power Generation



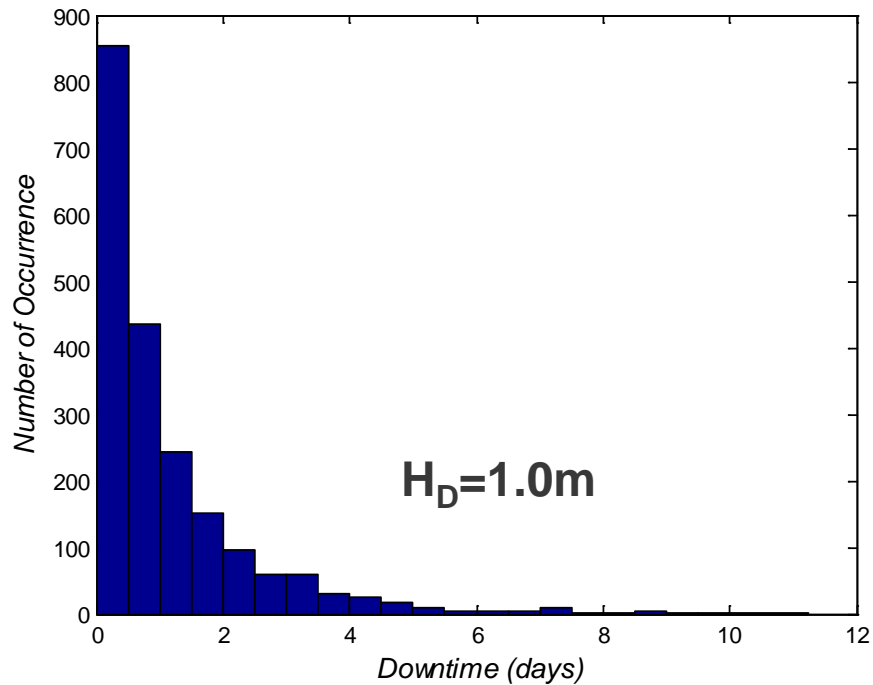
Changes in average power generation

	Yearly (Jan – Dec)		Summer (Jun – Aug)		Winter (Dec– Feb)	
	Power Output (GWh)	P-value	Power Output (GWh)	P-value	Power Output (GWh)	P-value
Control Average	1.9000		0.2471		0.5232	
Mean Difference (B1 minus Control)	-0.0403	0.1807	-0.0374	0.0002	0.0144	0.5348
Mean Difference (A1B minus Control)	-0.0410	0.3944	-0.0402	0.0002	0.0463	0.0613

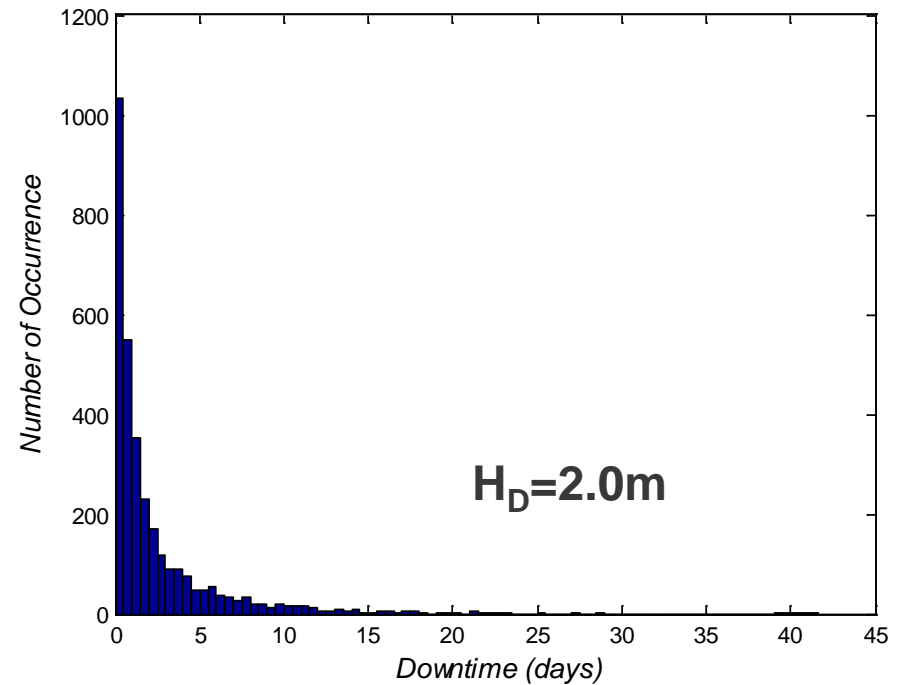
Downtime (Low) Definition



Histogram of Downtime (Control - 40 years)

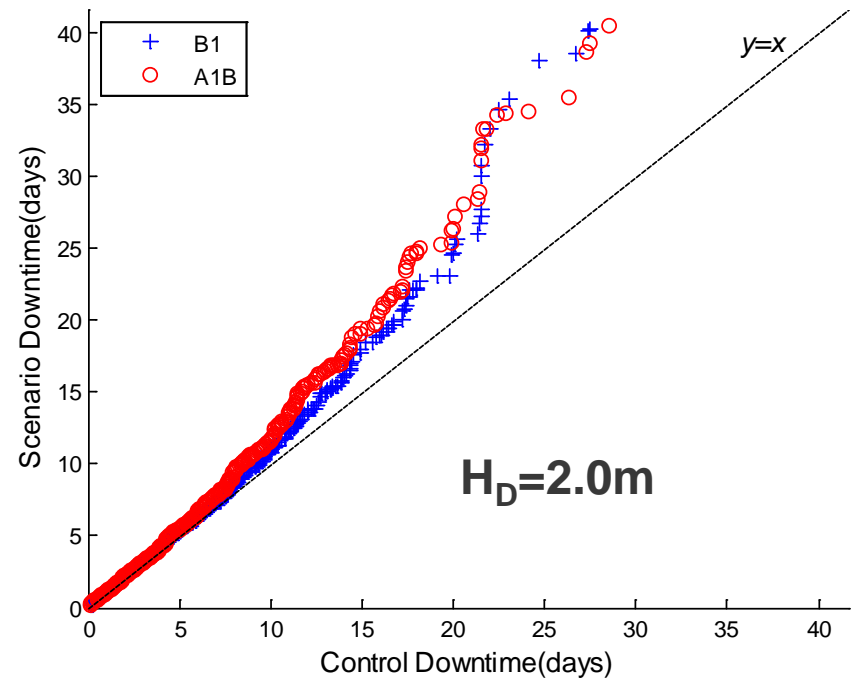
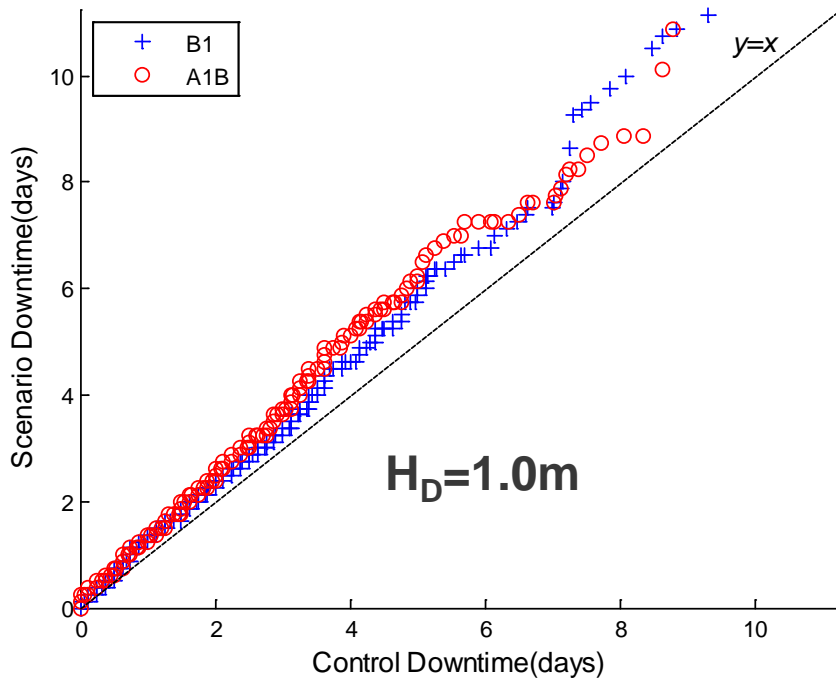


Mean Value=1.152d



Mean Value=2.421d

Changes in Downtime



Q-Q plot of probability distribution of down time between control and future scenarios

Conclusions at Wave Hub



- Future increase in mean and extreme H_s in winter
- Future decrease in mean H_s in summer
- Future increase in idle time and decrease in average power generation for *Pelamis* wave device in summer
- Future increase in downtime (low)

Summary for developers/ operators



Have demonstrated:

- i. method for modeling wave resource at Wave Hub
- ii. likely impact of climate change scenarios on this resource
- iii. how to estimate changes of idle time and power output of devices
- iv. patterns of changes in statistics of downtime

The method can be applied at other sites and for other devices!!



Thank you!