Marine Energy Sector Industry Use of Wave Data

Robin Stephens – ABPmer

Mark Calverley – Blue Ocean Consulting
IMarEST Offshore Renewables Special Interest Group

Gus Jeans – Oceanalysis
IMarEST Operational Oceanography Special Interest Group

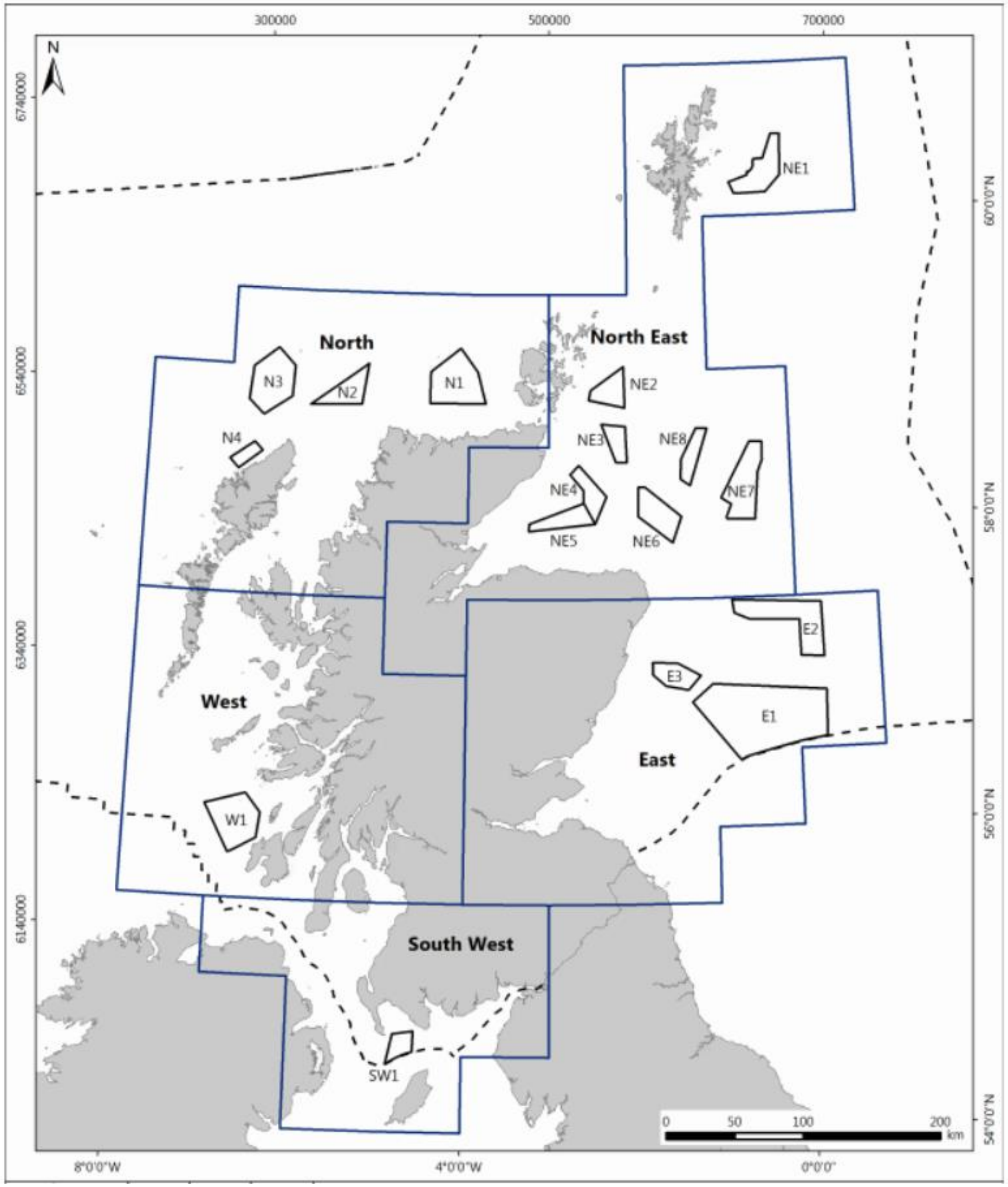
Contents

- Wave characterisation through the project lifecycle
- Wave data sources
- User engagement and case studies

Project Lifecycle

Source: IMarEST Metocean Procedures Guide for Offshore Renewables
www.imarest.org/reports/650-metocean-procedures-guide/file

Governmental Planning of License Concessions



Source: Marine Scotland Sectoral Marine Plan for Offshore Wind Energy

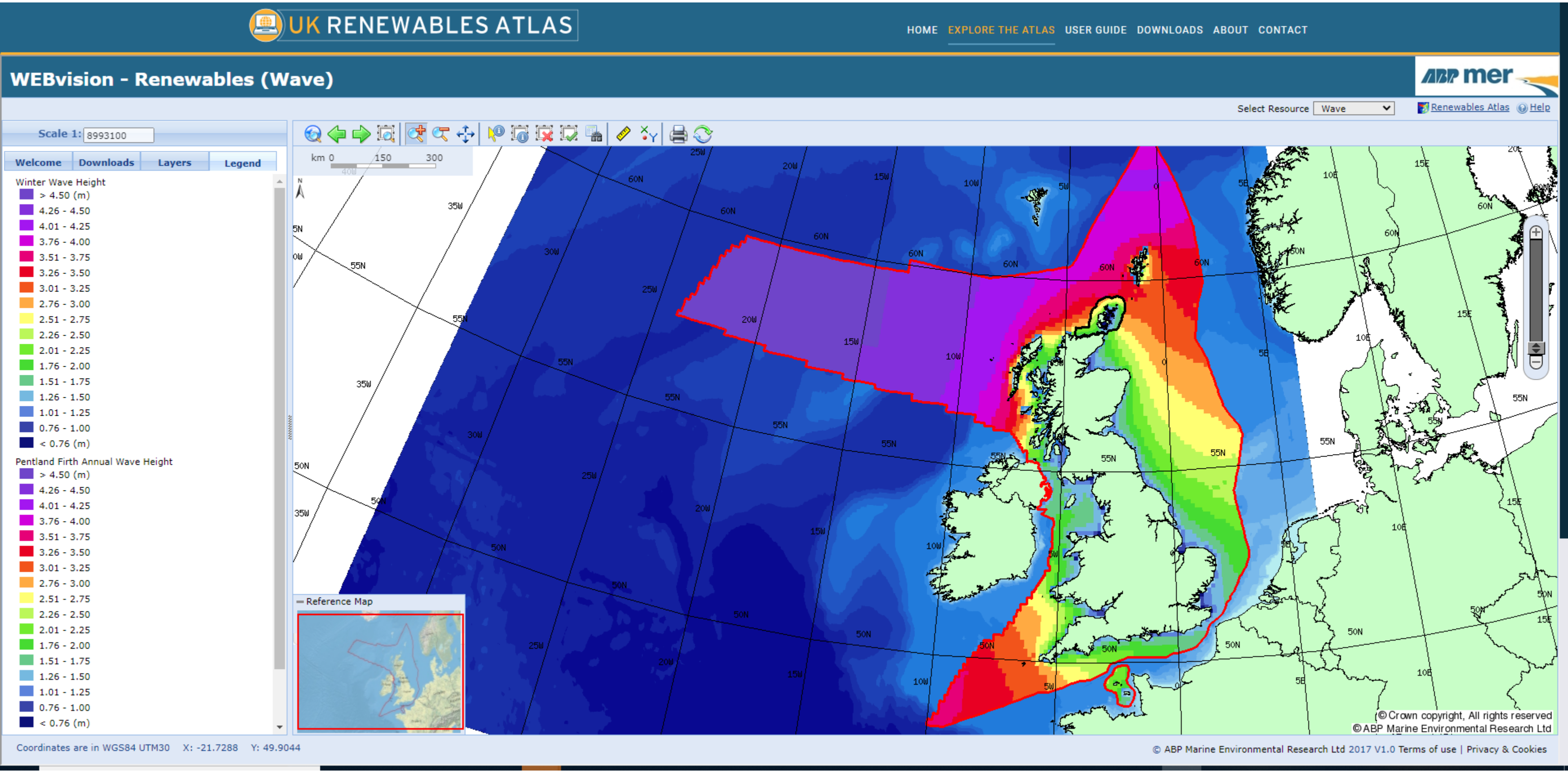
License Bidding

Resource evaluation

Feasibility assessment

Conceptual engineering

Cost estimation



Source: The Atlas of UK Marine Renewables Energy Resources

Preliminary Engineering

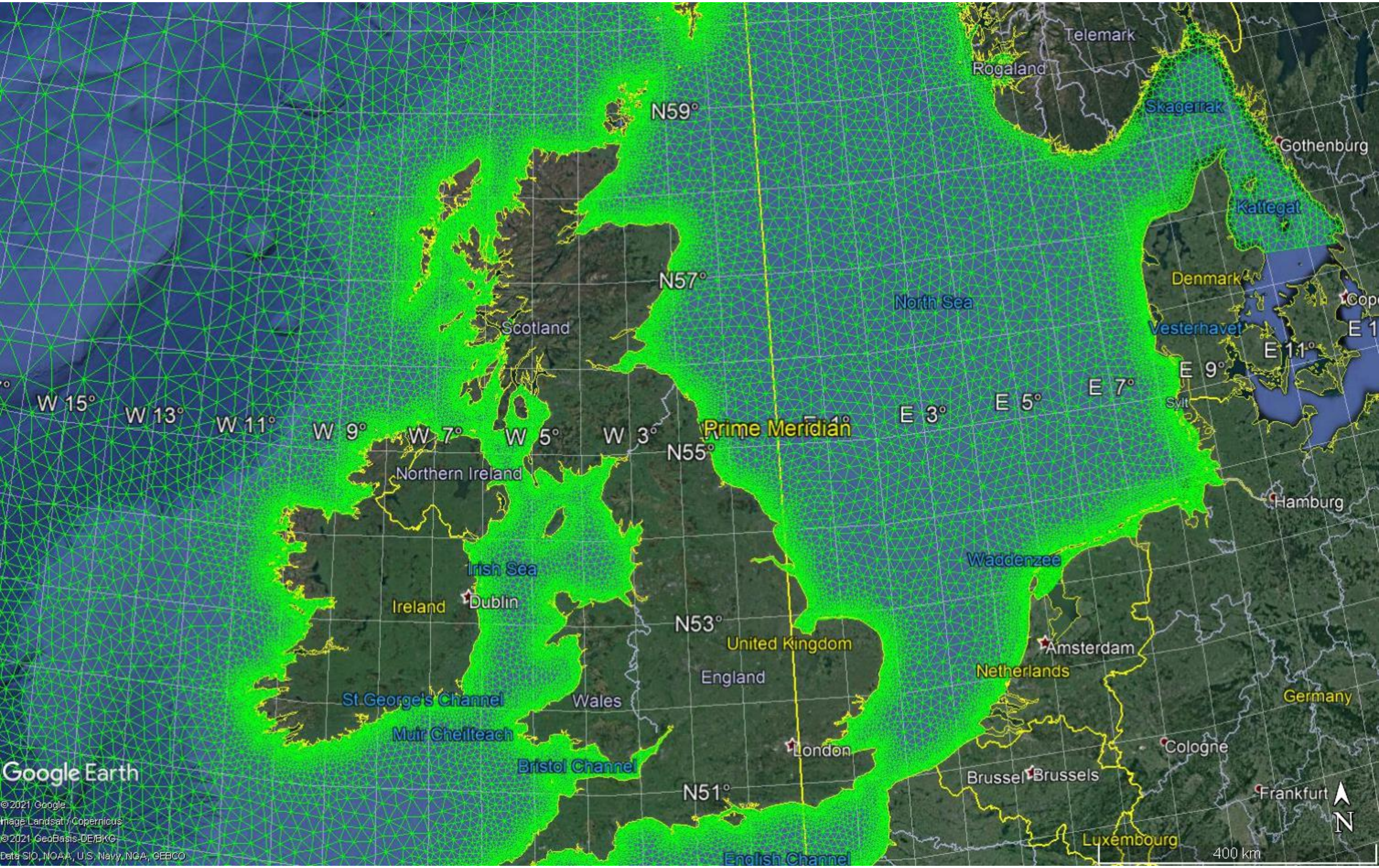
Source: U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy

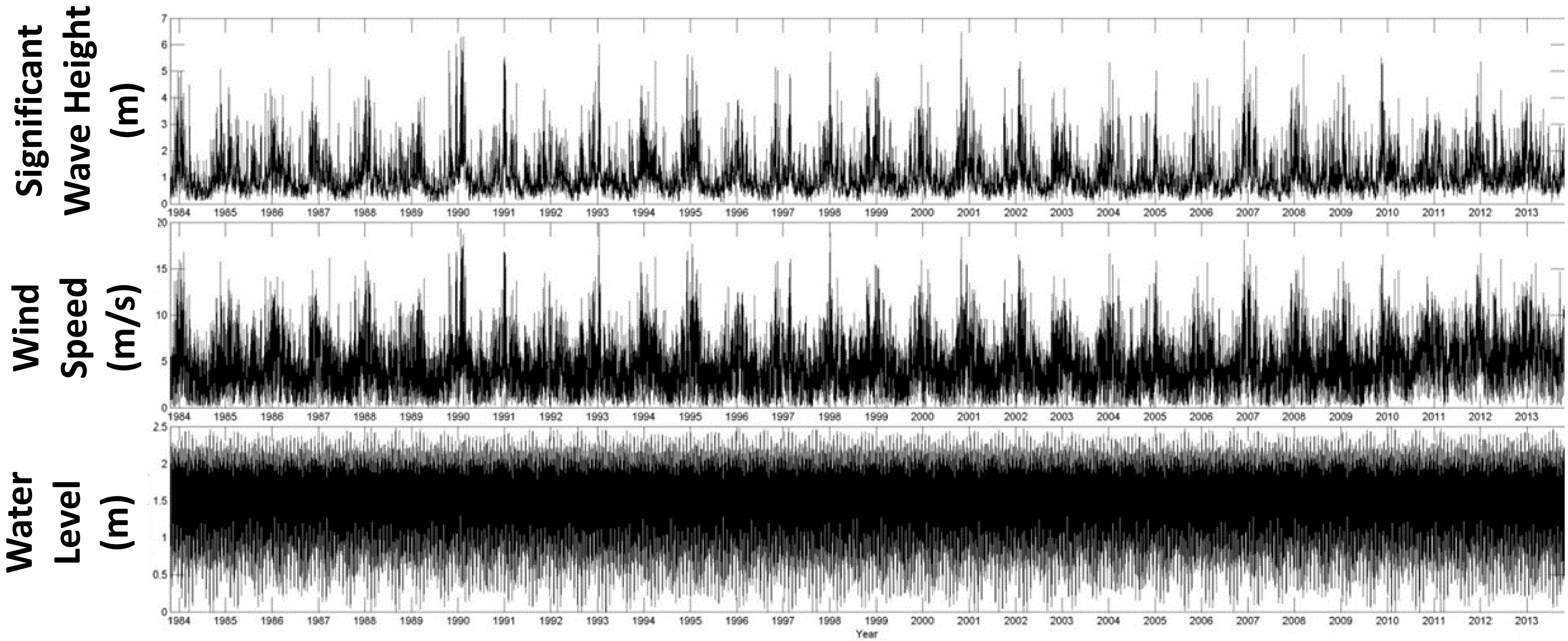
Wave Criteria for Engineering Design

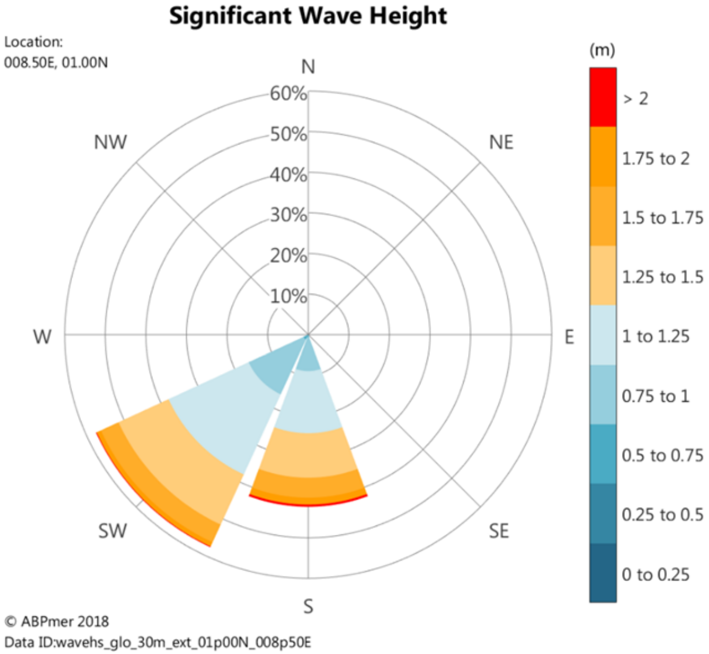
Annual Omnidirectional Waves				
	Return Period (years)			
	1	10	50	100
Hs (m)	7.7	9.6	10.5	10.8
Tz (s)	7.9	8.9	9.3	9.4
Tp (s)	10.3	11.5	12.1	12.2
Hmax (m)	16.1	20.2	22.0	22.6
Tass (s)	11.0	12.4	12.9	13.1
Cmax (m)	10.0	12.7	13.8	14.2

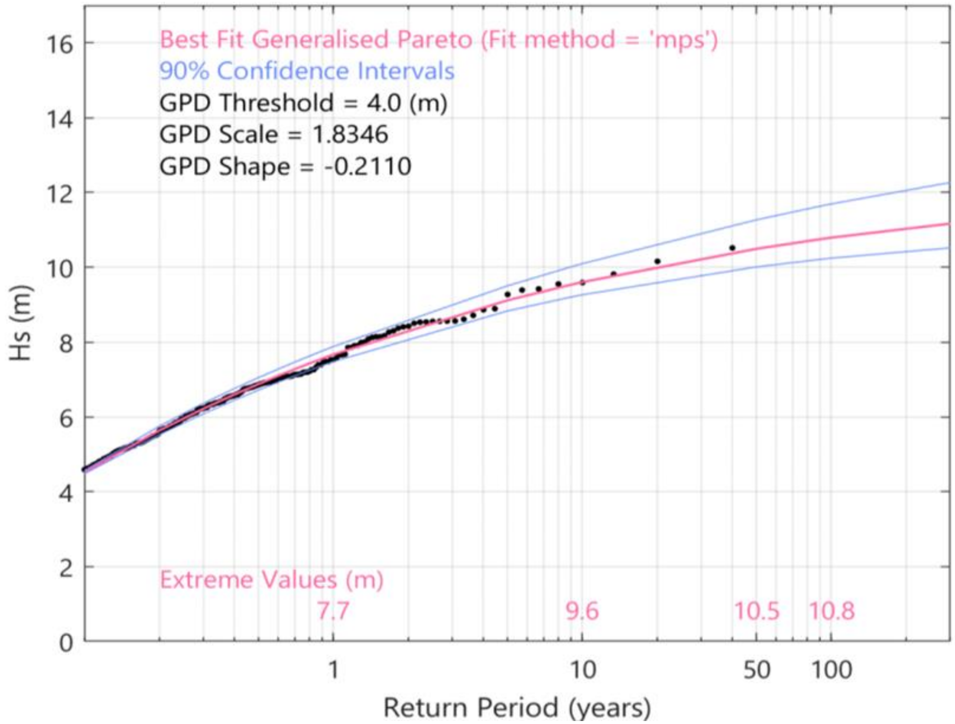
Distribution of Individual Wave Heights for Fatigue (1-Year) — **Directions are FROM**

H_lower (m)	H_upper (m)	N	NE	E	SE	S	SW	W	NW	OMNI	Tz (s)
0.0	0.5	2,133,210	45,190	33,305	136,335	123,975	40,149	2,289	7,767	2,522,220	4.1
0.5	1.0	1,926,498	38,335	39,717	121,607	125,903	24,741	1,761	5,650	2,284,212	4.6
1.0	1.5	848,090	14,888	22,833	53,274	61,706	7,934	779	2,500	1,012,004	5.2
1.5	2.0	388,669	6,112	12,202	25,693	30,935	3,141	343	1,181	468,276	5.5
2.0	2.5	185,659	2,759	6,593	13,245	16,097	1,379	152	562	226,446	5.8
2.5	3.0	94,712	1,419	3,711	7,252	8,801	655	69	275	116,894	6.1
3.0	3.5	50,924	794	2,159	4,111	4,973	329	33	140	63,463	6.3
3.5	4.0	28,603	466	1,292	2,391	2,889	174	16	75	35,906	6.5
4.0	4.5	16,635	282	789	1,420	1,720	96	9	41	20,992	6.7
4.5	5.0	9,940	173	488	857	1,048	56	5	23	12,590	6.9
5.0	5.5	6,069	107	304	525	652	33	3	13	7,706	7.1
5.5	6.0	3,769	67	190	326	413	20	2	7	4,794	7.2
6.0	6.5	2,373	42	119	205	265	13	1	4	3,022	7.3
6.5	7.0	1,511	27	74	130	172	8	1	2	1,925	7.5
7.0	7.5	972	17	46	83	112	5		1	1,236	7.6
7.5	8.0	630	11	28	54	73	3		1	800	7.7
8.0	8.5	411	7	17	35	48	2			520	7.8
8.5	9.0	270	4	10	23	31	1			339	7.9
9.0	9.5	179	3	6	15	21	1			225	7.9
9.5	10.0	119	2	4	10	14	1			150	8.0
10.0	10.5	79	1	2	6	9				97	8.1
10.5	11.0	53	1	1	4	6				65	8.2
11.0	11.5	36		1	3	4				44	8.3
11.5	12.0	24			2	3				29	8.3
12.0	12.5	16			1	2				19	8.4
12.5	13.0	11			1	1				13	8.5
13.0	13.5	7				1				8	8.5
13.5	14.0	5				1				6	8.6
14.0	14.5	3								3	8.6
14.5	15.0	2								2	8.7
15.0	15.5	2								2	8.7
15.5	16.0	1								1	8.7
		5,699,482	110,707	123,891	367,608	379,875	78,741	5,463	18,242	6,784,009	

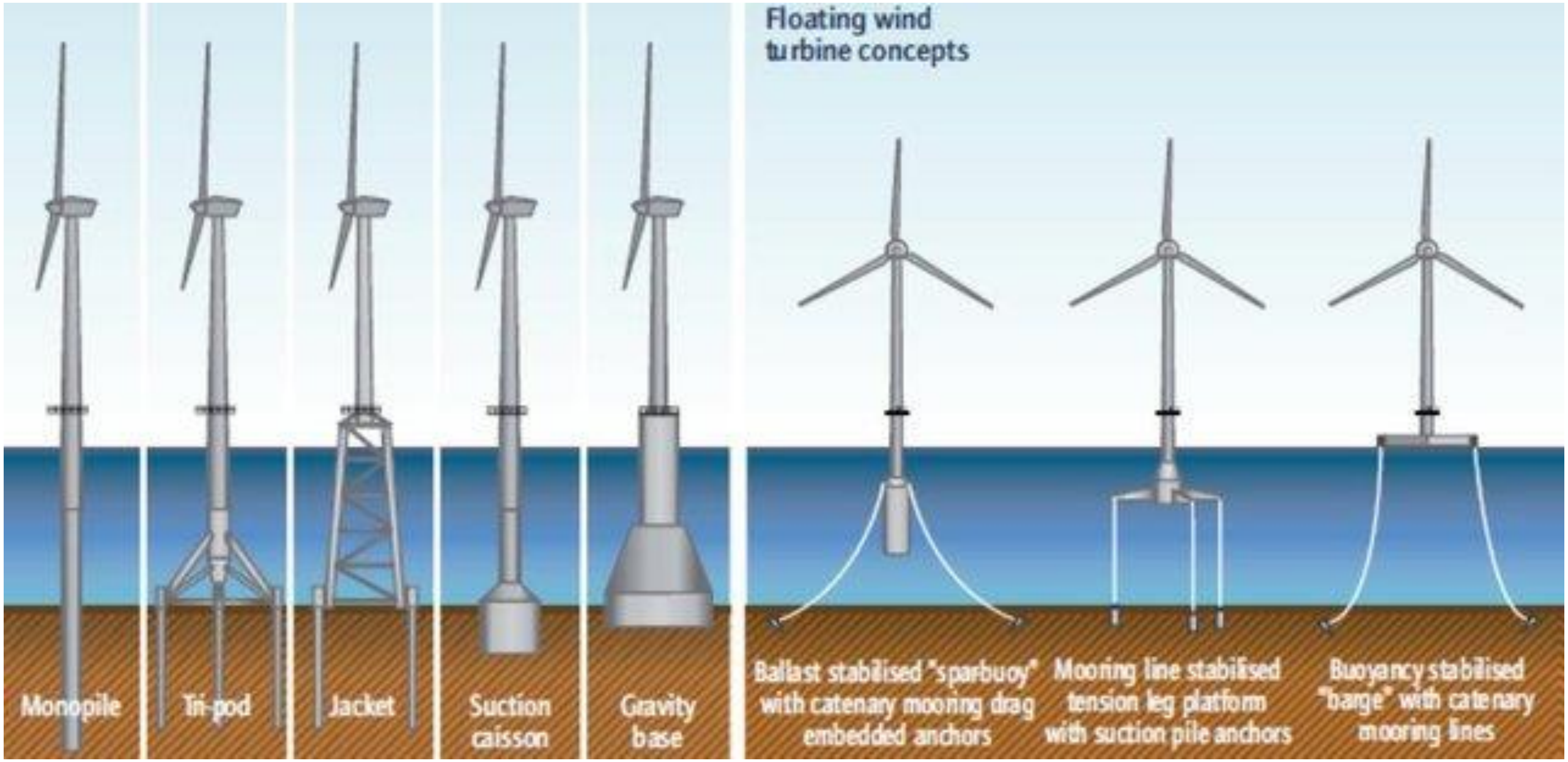

N59°
N57°
N55°
N53°
N51°
W 15°
W 13°
W 11°
W 9°
W 7°
W 5°
W 3°
E 3°
E 5°
E 7°
E 9°
E 11°
Prime Meridian
Telemark
Rogaland
Skagerrak
Gothenburg
Kattegat
Denmark
North Sea
Vesterhavet
Sylt
Scotland
Northern Ireland
Irish Sea
Ireland
Dublin
United Kingdom
England
Wales
St George's Channel
Muir Cheilteach
Bristol Channel
London
English Channel
Hamburg
Waddenzee
Amsterdam
Netherlands
Germany
Cologne
Brussel Brussels
Frankfurt
Luxembourg
400 km
N
Google Earth
© 2021 Google
Image Landsat / Copernicus
© 2021 GeoBasis-DE/BKG
Data SIO, NOAA, U.S. Navy, NGA, GEBCO


Significant Wave Height (m)
Wind Speed (m/s)
Water Level (m)
Year

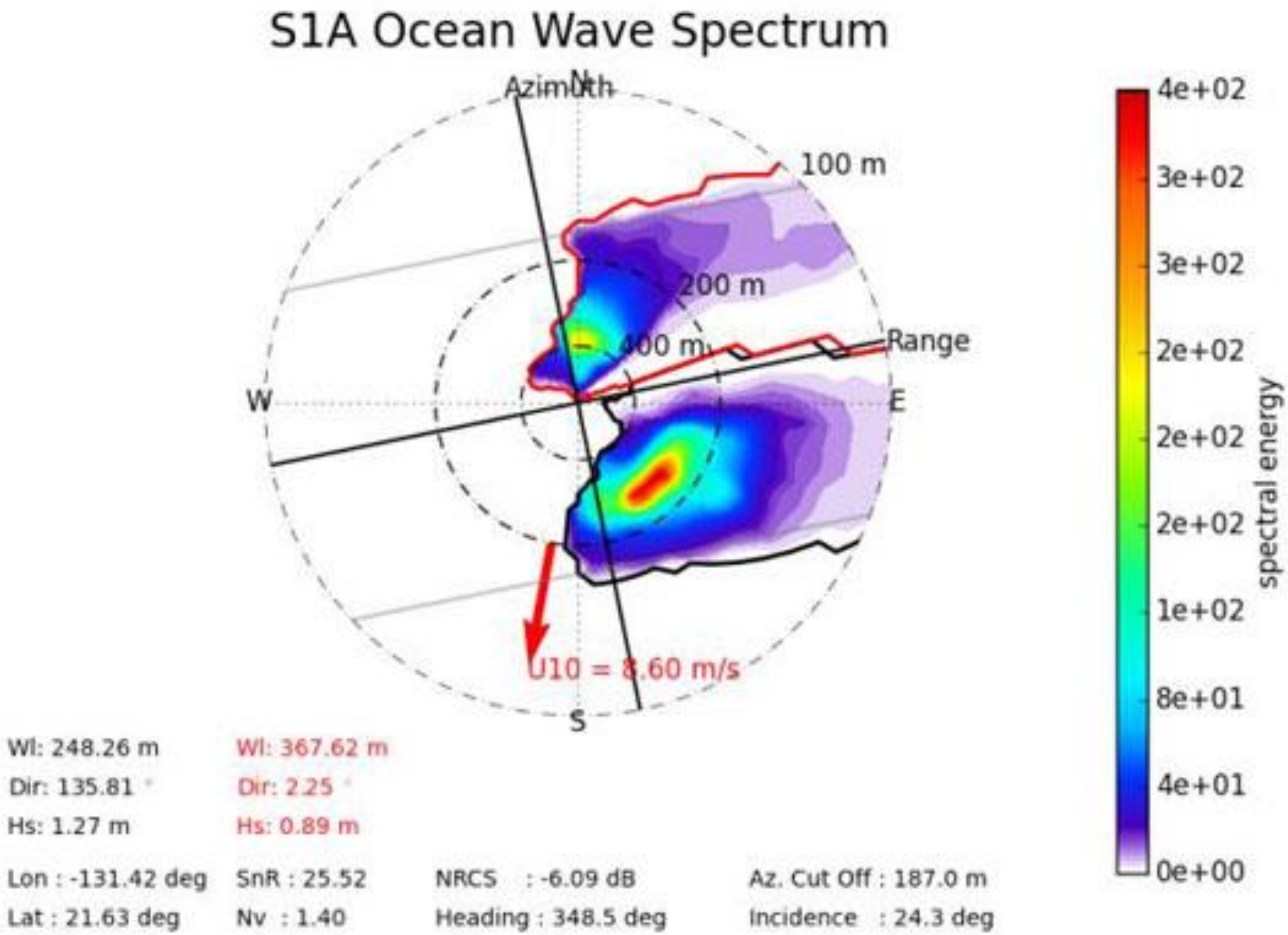

Significant Wave Height
Location:
008.50E, 01.00N
N
NE
E
SE
S
SW
W
NW
60%
50%
40%
30%
20%
10%
(m)
> 2
1.75 to 2
1.5 to 1.75
1.25 to 1.5
1 to 1.25
0.75 to 1
0.5 to 0.75
0.25 to 0.5
0 to 0.25
© ABPmer 2018
Data ID:wavehs_glo_30m_ext_01p00N_008p50E


Best Fit Generalised Pareto (Fit method = 'mps')
90% Confidence Intervals
GPD Threshold = 4.0 (m)
GPD Scale = 1.8346
GPD Shape = -0.2110
Hs (m)
16
14
12
10
8
6
4
2
0
Extreme Values (m)
7.7
9.6
10.5
10.8
1
10
50
100
Return Period (years)

More floating structures
Increased sensitivity to wave motion
Quantitation of wave energy by period and direction
Full directional wave spectra



Source: E I Konstantinidis and P N Botsaris 2016 IOP Conf. Ser.: Mater. Sci. Eng. 161 012079.
Wind turbines: current status, obstacles, trends and technologies. DOI: 10.1088/1757-899X/161/1/012079



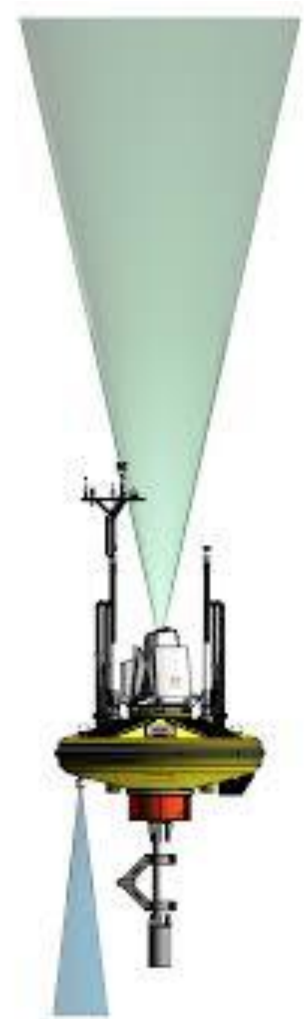
https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/product-types-processing-levels/level-2

Detailed Engineering Design and Certification

STANDARD	FULL REFERENCE
ISO 19901-1:2015	International Organization for Standardization (2015). International Standard, Petroleum and natural gas industries - Specific requirements for offshore structures - Part 1: Metocean design and operating considerations. Second edition, 2015-10-15, ISO 19901-1:2015.
DNVGL-RP-C205	DNVGL (2017). Recommended Practice, Environmental Conditions and Environmental Loads, August 2017, DNVGL-RP-C205.
IEC 61400-3:2009	International Electrotechnical Commission (2009). International Standard, Wind turbines - Part 3: Design requirements for offshore wind turbines, Edition 1.0, 2009-02, IEC 61400-3:2009.
IEC TS 62600-2:2016	International Electrotechnical Commission (2016). Technical Specification IEC TS 62600-2:2016. Marine energy - Wave, tidal and other water current converters - Part 2: Design Requirements for marine energy systems.

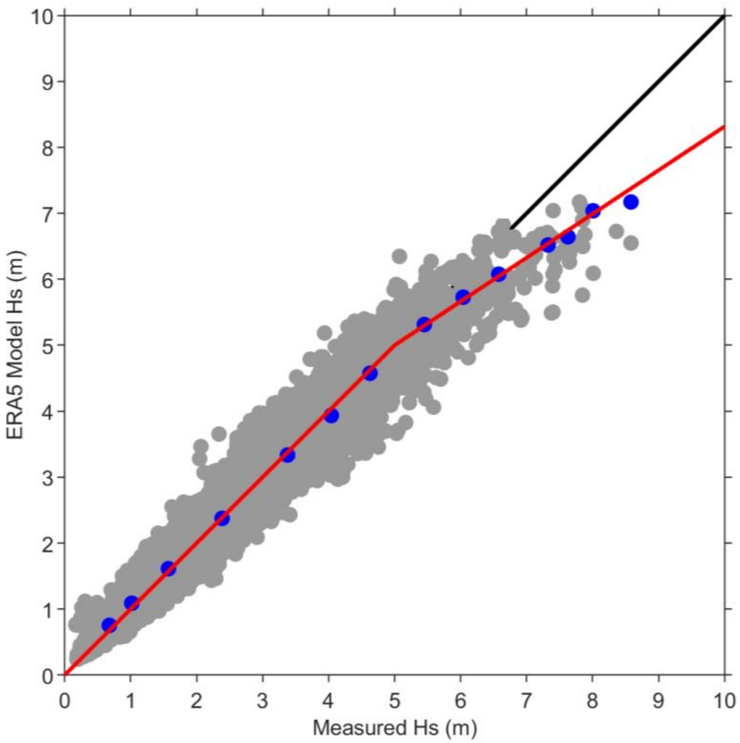
Source: IMarEST Metocean Procedures Guide for Offshore Renewables
www.imarest.org/reports/650-metocean-procedures-guide/file

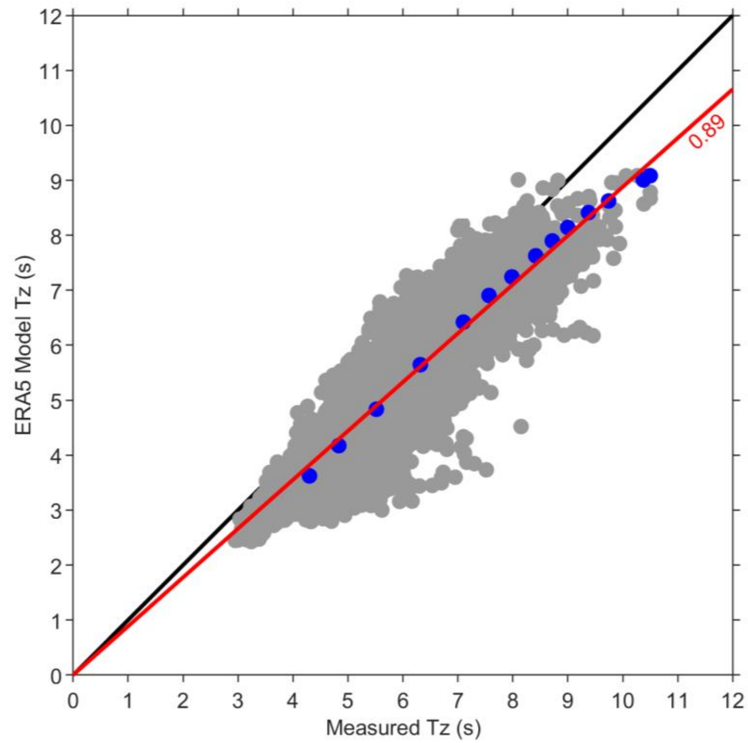
In-Situ Measurements



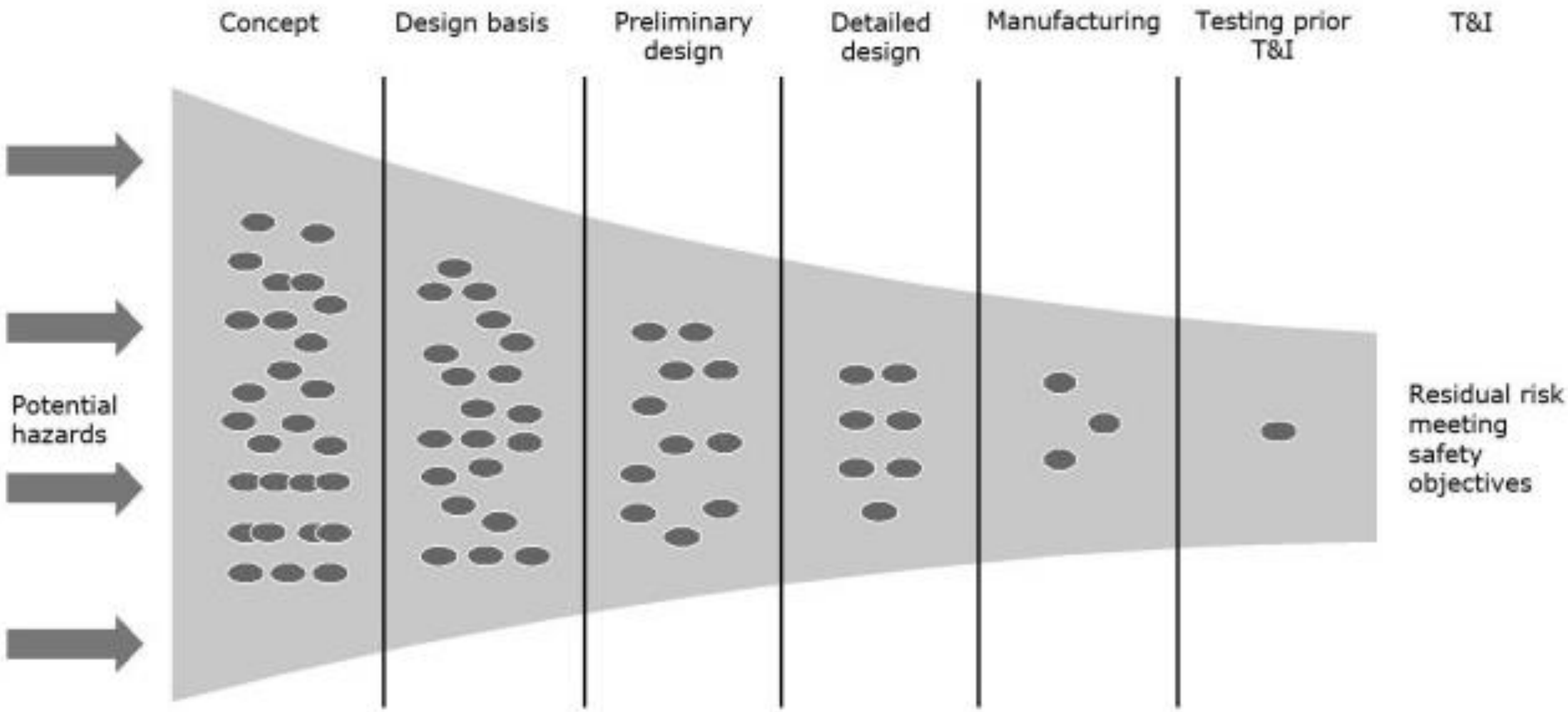
Source: Fugro

Validation



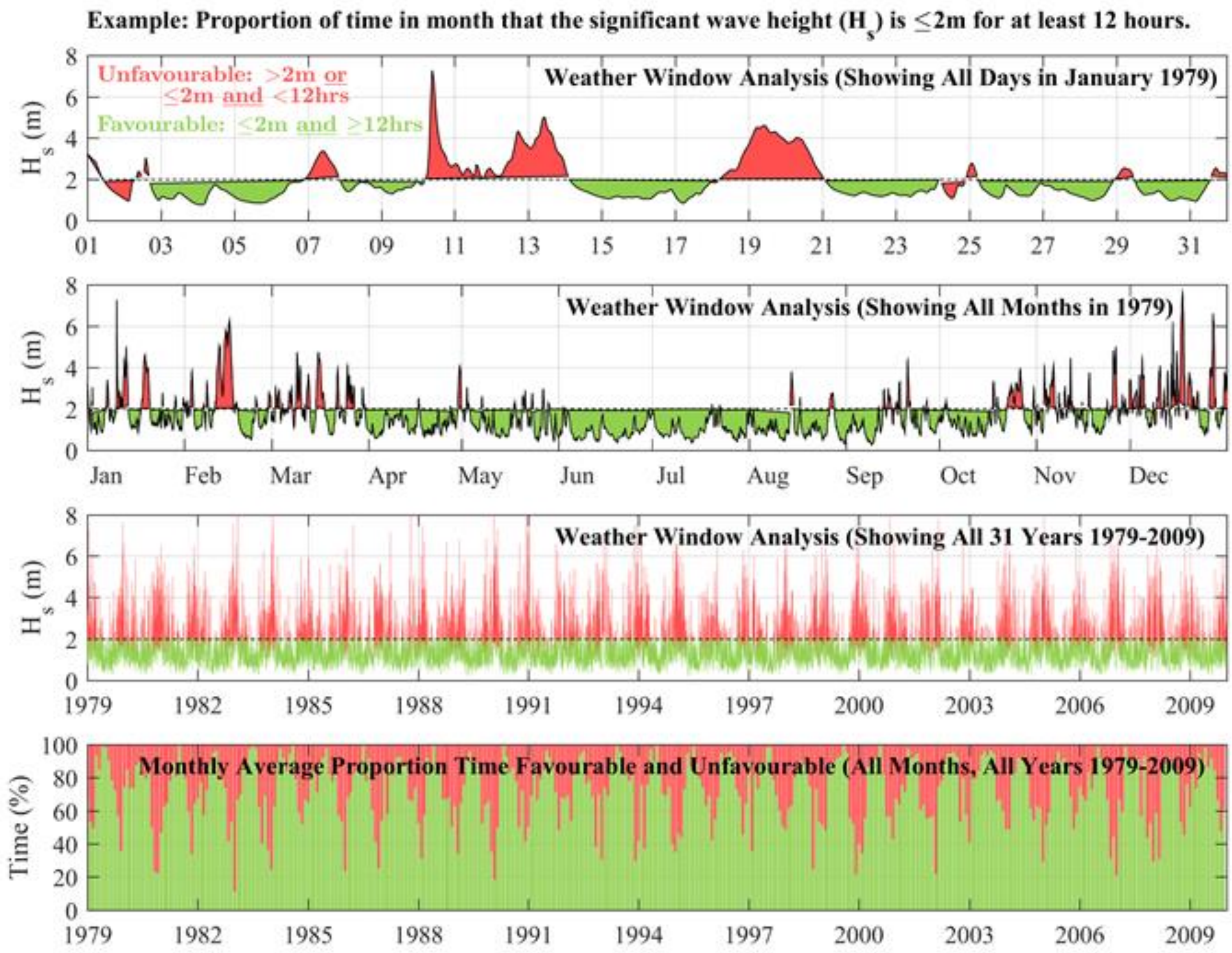


Progressively Reducing Uncertainty



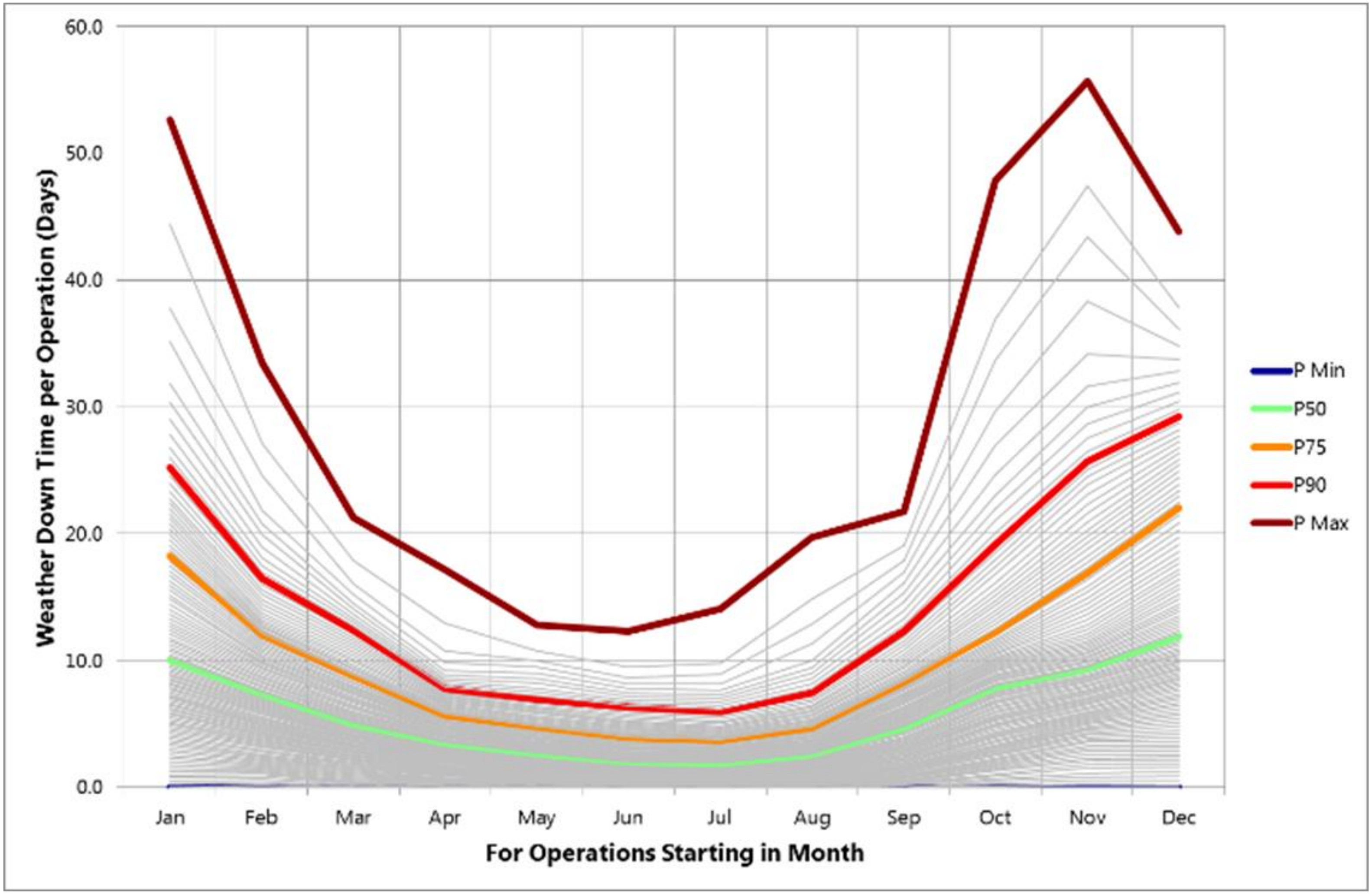
Source: DNVGL-ST-0054

Installation

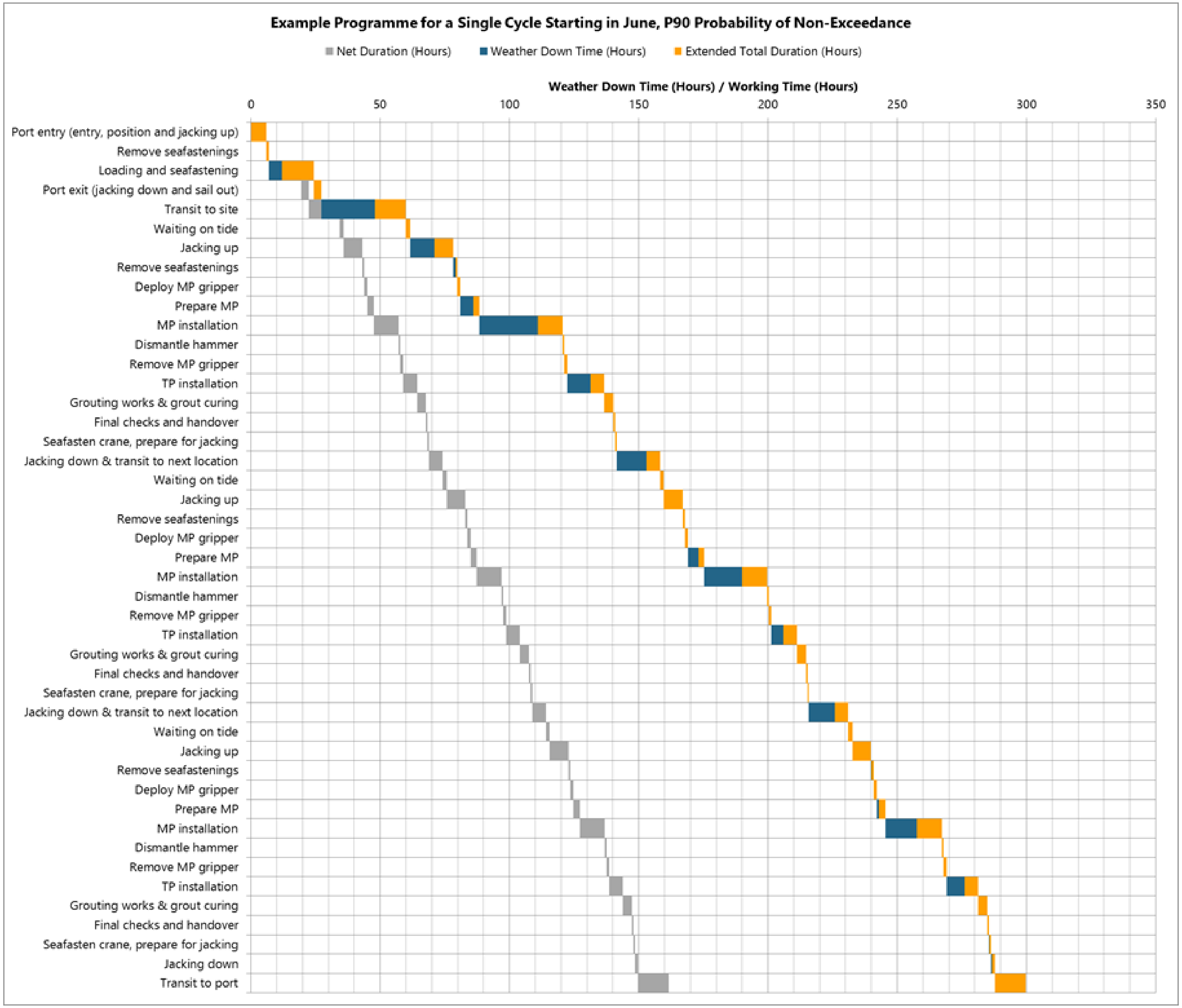


Example: Proportion of time in month that the significant wave height (H_s) is ≤2m for at least 12 hours.
Unfavourable: >2m or ≤2m and <12hrs
Favourable: ≤2m and ≥12hrs
Weather Window Analysis (Showing All Days in January 1979)
Weather Window Analysis (Showing All Months in 1979)
Weather Window Analysis (Showing All 31 Years 1979-2009)
Monthly Average Proportion Time Favourable and Unfavourable (All Months, All Years 1979-2009)
H_s (m)
Time (%)

Tasks	**Location**			**Durations**		**Thresholds (not to be exceeded whilst working)**						
Task name	**Location of task**			**Task dur**	**Weather**	**Wave heigh**	**Wave perio**	**Wave perio**	**Wind speed**	**Wind ref. h**	**Wind avg. p**	**Current spe**
	Longitud	**Latitude**	**Client da**	**(hrs)**	**(hrs)**	**(m)**	**(s)**	**Allow work**	**(m/s)**	**(m)**	**(s)**	**(m/s)**
Enter port and position	8.267	55.445		3	3.5	3			15	10	60	
Jack up in port	8.43	55.468		6	8				12	10	60	
Prepare crane	8.43	55.468		0.5	1				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG blade	8.43	55.468		1	2				12	100	60	
Load WTG nacelle	8.43	55.468		2	3				12	100	60	
Load WTG nacelle	8.43	55.468		2	3				12	100	60	
Load WTG nacelle	8.43	55.468		2	3				12	100	60	
Load WTG tower	8.43	55.468		3	5				12	100	60	
Load WTG tower	8.43	55.468		3	5				12	100	60	
Load WTG tower	8.43	55.468		3	5				12	100	60	
Stow crane	8.43	55.468		0.5	1				12	100	60	
Jack down in port	8.43	55.468		6	8				12	10	60	
Transit Leg 1	7.853	55.23		4	6	3						
Transit Leg 2	6.708	54.782		4	6	3						
Transit Leg 3	5.611	54.4		4	6	3						
Jack up on site	4.94	54.129		8	10	2	14		14	10	60	1
Prepare crane	4.94	54.129		0.5	1				12	100	60	



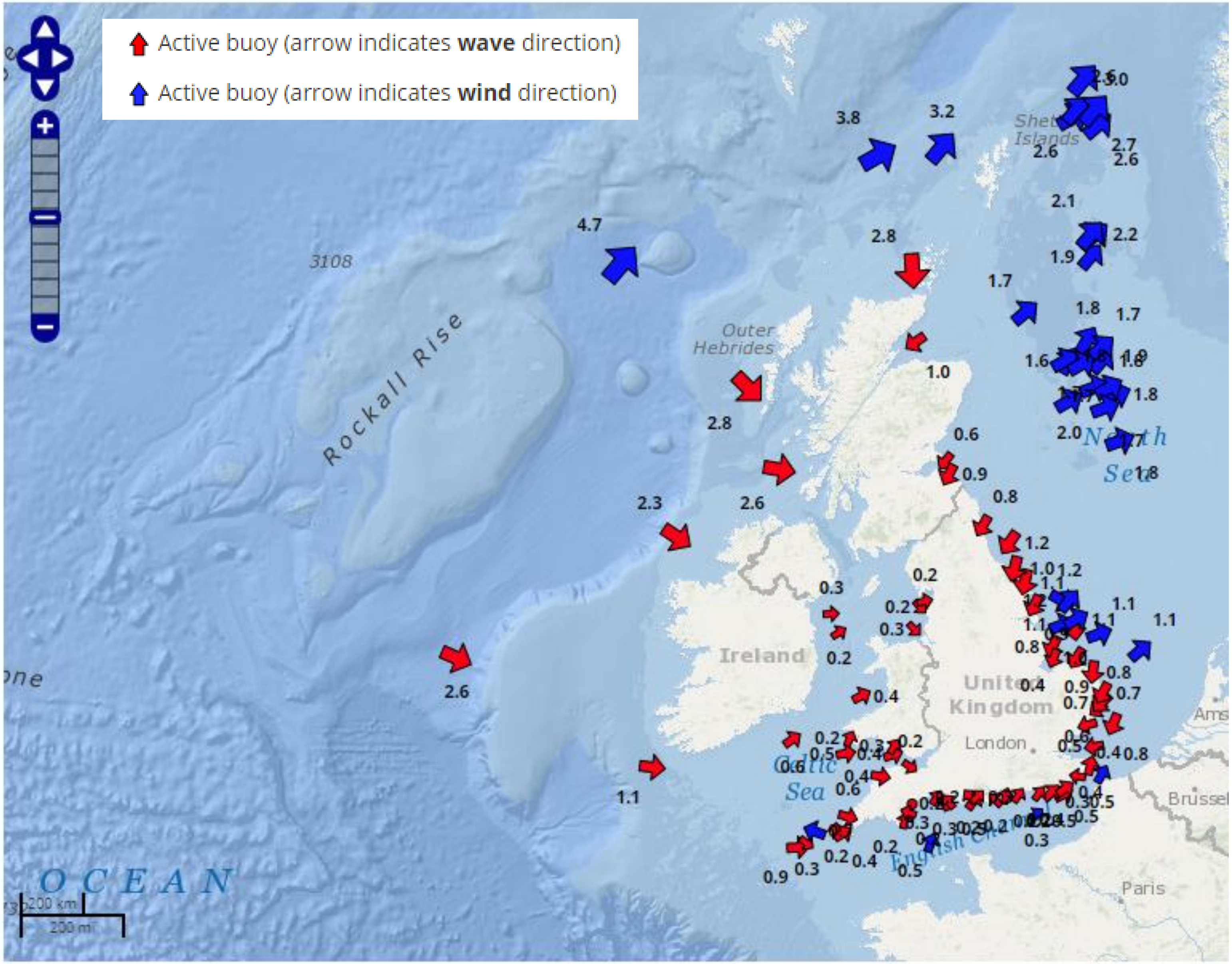
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Weather Down Time per Operation (Days)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
For Operations Starting in Month
P Min
P50
P75
P90
P Max



Example Programme for a Single Cycle Starting in June, P90 Probability of Non-Exceedance
Net Duration (Hours)
Weather Down Time (Hours)
Extended Total Duration (Hours)
Weather Down Time (Hours) / Working Time (Hours)
0
50
100
150
200
250
300
350
Port entry (entry, position and jacking up)
Remove seafastenings
Loading and seafastening
Port exit (jacking down and sail out)
Transit to site
Waiting on tide
Jacking up
Remove seafastenings
Deploy MP gripper
Prepare MP
MP installation
Dismantle hammer
Remove MP gripper
TP installation
Grouting works & grout curing
Final checks and handover
Seafasten crane, prepare for jacking
Jacking down & transit to next location
Waiting on tide
Jacking up
Remove seafastenings
Deploy MP gripper
Prepare MP
MP installation
Dismantle hammer
Remove MP gripper
TP installation
Grouting works & grout curing
Final checks and handover
Seafasten crane, prepare for jacking
Jacking down & transit to next location
Waiting on tide
Jacking up
Remove seafastenings
Deploy MP gripper
Prepare MP
MP installation
Dismantle hammer
Remove MP gripper
TP installation
Grouting works & grout curing
Final checks and handover
Seafasten crane, prepare for jacking
Jacking down
Transit to port

Operations & Maintenance

Source: Incat Crowther



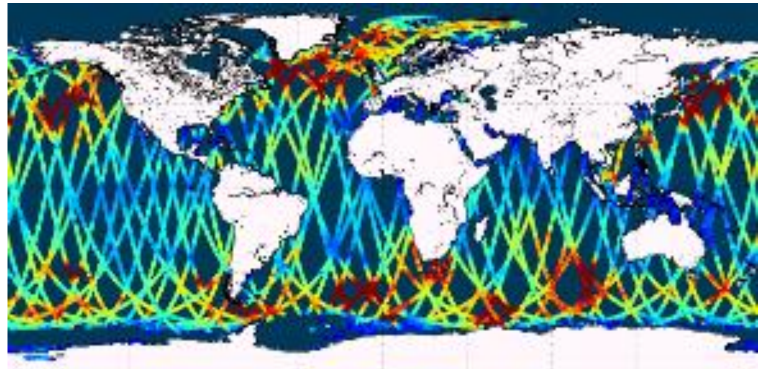
Cefas

Real time data from Cefas WaveNet at 1400 on 22 March 2021
http://wavenet.cefas.co.uk/Map

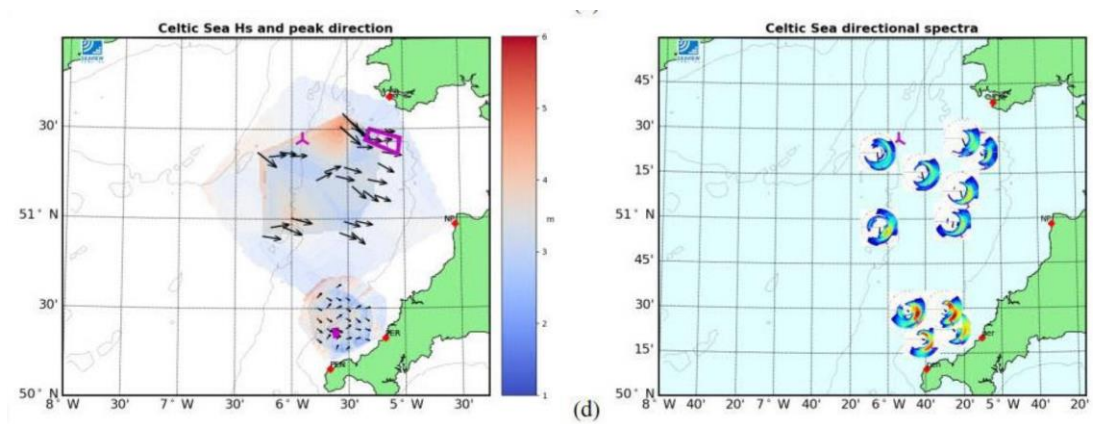
DELIVERABLE	ACTIVITIES	SITE SELECTION AND FEASIBILITY	DEVELOPMENT AND CONSENTS	DESIGN AND CERTIFICATION	INSTALLATION	O&M	DECOMMISSIONING
Metocean briefing note	Literature review[D]	■					
	Data collation from free sources and gap analysis[D]	■					
Preliminary engineering dataset and analyses	Purchase of data[D]		■				
	Modelling[M] (calibrated with publicly available data or uncalibrated)		■				
	Data analysis[D]		■	■			
	Environmental impact analysis[DMS]		■				
Full engineering dataset and analyses	*In-situ* measurement[S]		■	■			
	Fully calibrated modelling[M]			■			
	Data analysis[D]			■	■	■	■
Other	Weather forecast modelling[M]				■	■	■
	Real-time *in-situ* measurement[S]				■	■	■
	Strategy optimisation and condition monitoring[DMS]					■	
	End of life assessment					■	

Source: IMarEST Metocean Procedures Guide for Offshore Renewables
www.imarest.org/reports/650-metocean-procedures-guide/file

Sources of wave data

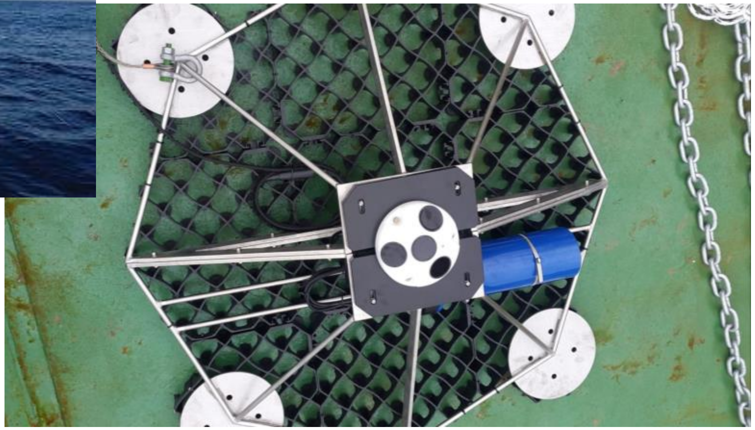


Remote sensing data



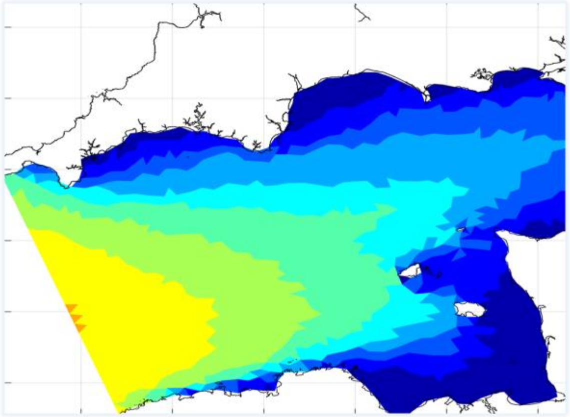
'Provided by Lucy Wyatt, Seaview Sensing Ltd', doi:10.21926/jept.2101005

Sources of Wave Data

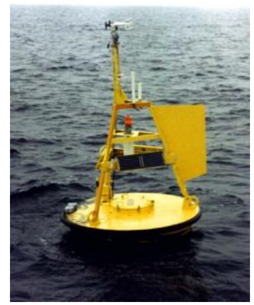


In-situ data

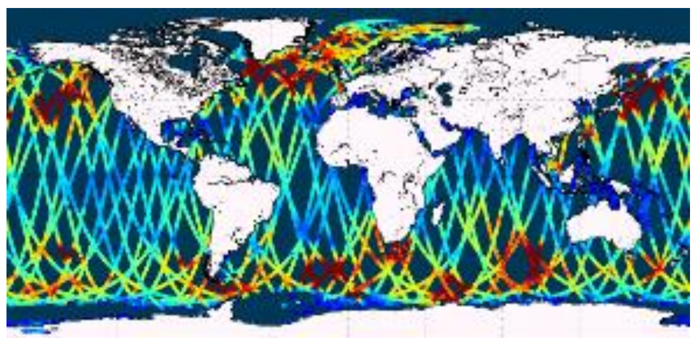
Modelled data

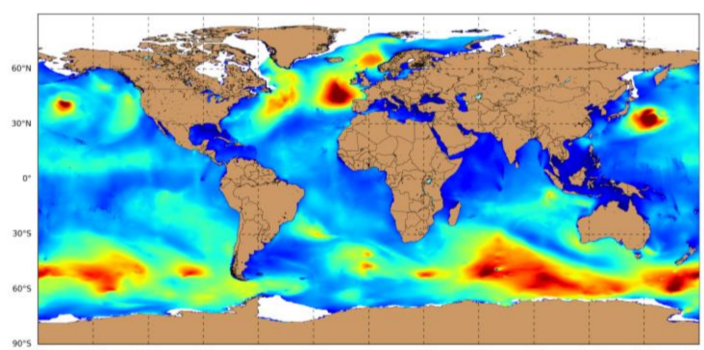


Validation



https://www.ndbc.noaa.gov/hull.shtml





Types of wave data

Parameter data

Total energy: Hs, Hmax, Hc, Tz, Tp, θpeak

Partitioned Parameter data

Wind sea: Hs, Hmax, Hc, Tz, Tp, θpeak

Swell 1: Hs, Hmax, Hc, Tz, Tp, θpeak

Swell 2: Hs, Hmax, Hc, Tz, Tp, θpeak

Spectral Data

Omnidirectional

Directional

For engineering and operational planning, data types highlighted in green are required.

Source	Total energy parameters	Partitioned parameters	Omnidirectional spectra	Directional spectra
Altimeter	Y[1]			
SAR	Y[2]	Y[2]	Y[2]	Y[2]
HF Radar	Y	Y	Y	Y
Vertical Radar	Y	Y		
Wave buoy	Y	Y	Y	Y
ADCP	Y	Y	Y	Y
Pressure sensor	Y	Y	Y	
Model	Y	Y	Y	Y

Notes

1. Altimeter data only provide significant wave height
2. SAR provides limited coverage of spectra in both wave period and direction

Temporal considerations

Sampling interval

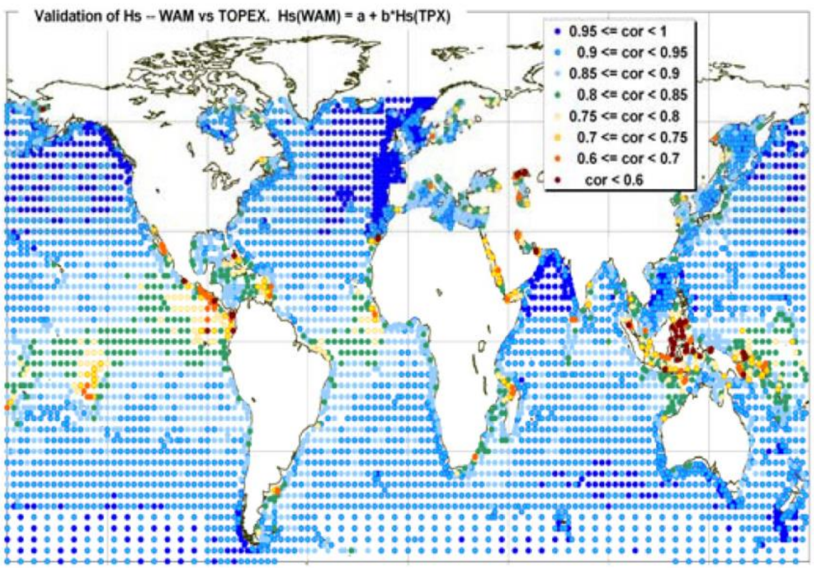
A high sampling interval (10-30-mins) is required to properly capture extreme events and support operational analyses such as weather windows.

Duration

A long time series (20-30 years) is required to capture a number of extreme events for design and to characterise inter-annual variability for operating and maintenance planning.

Limits value of 10-14 day repeat cycle data.

Validation of model data at large scale – application to wave resource modelling



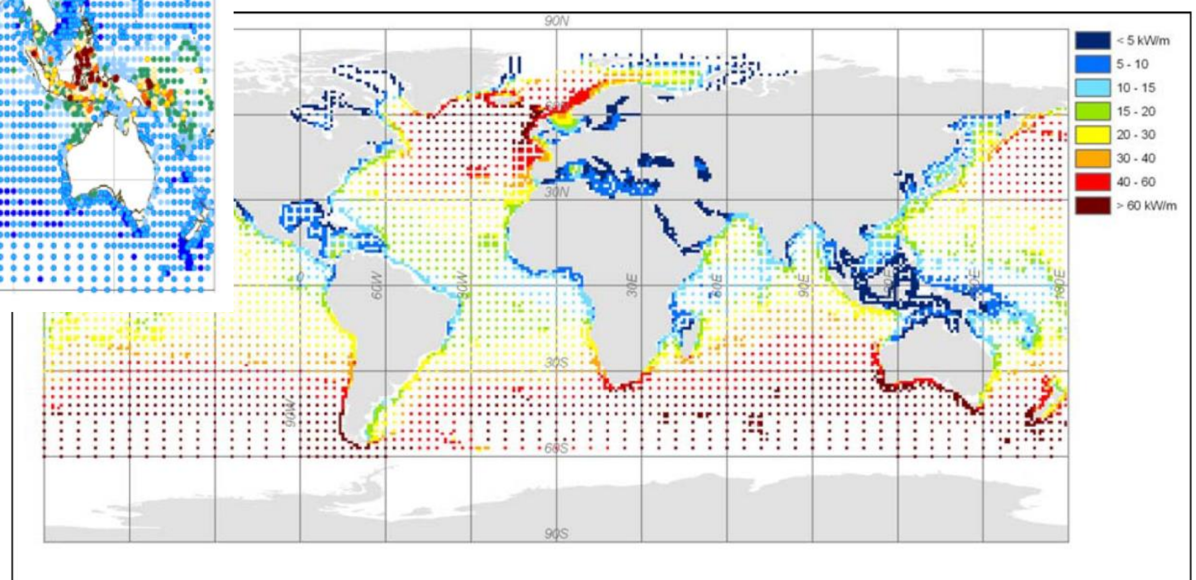


Figure 2 – Annual global gross theoretical wave power for all WorldWaves grid points worldwide.

ESA SeaState CCI

Some potential roles

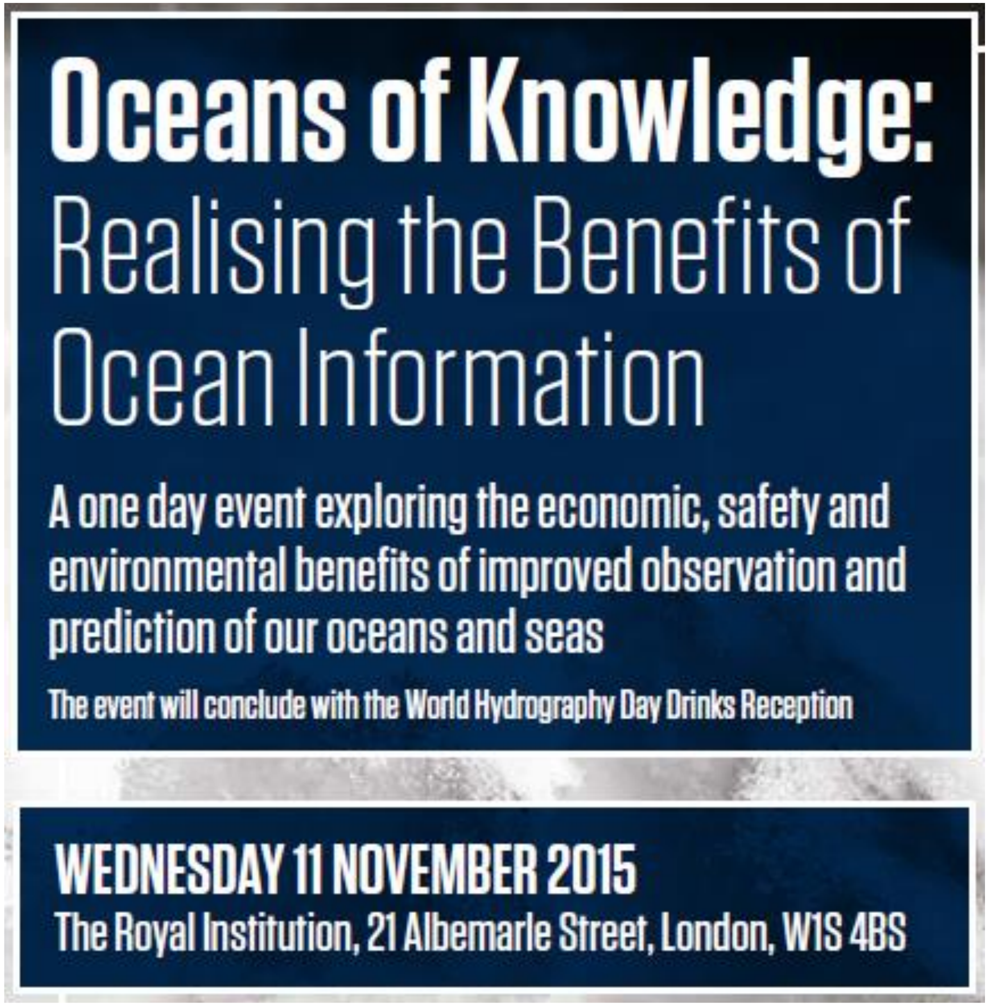
Improving temporal consistency of re-analysis data sets

Ability to support early phase validation of wave energy resource modelling, using shoreward along track data

Reduce swell related uncertainty in global numerical models

Verification of spectral shape for early validation of deepwater modelling for floating wind

2015 : Bring Together Wide Range of Users



User Case Studies

Oil & Gas

Oil Spill Response

Offshore Renewables

Ports & Harbours

Coastal Flood Risk

Insurance

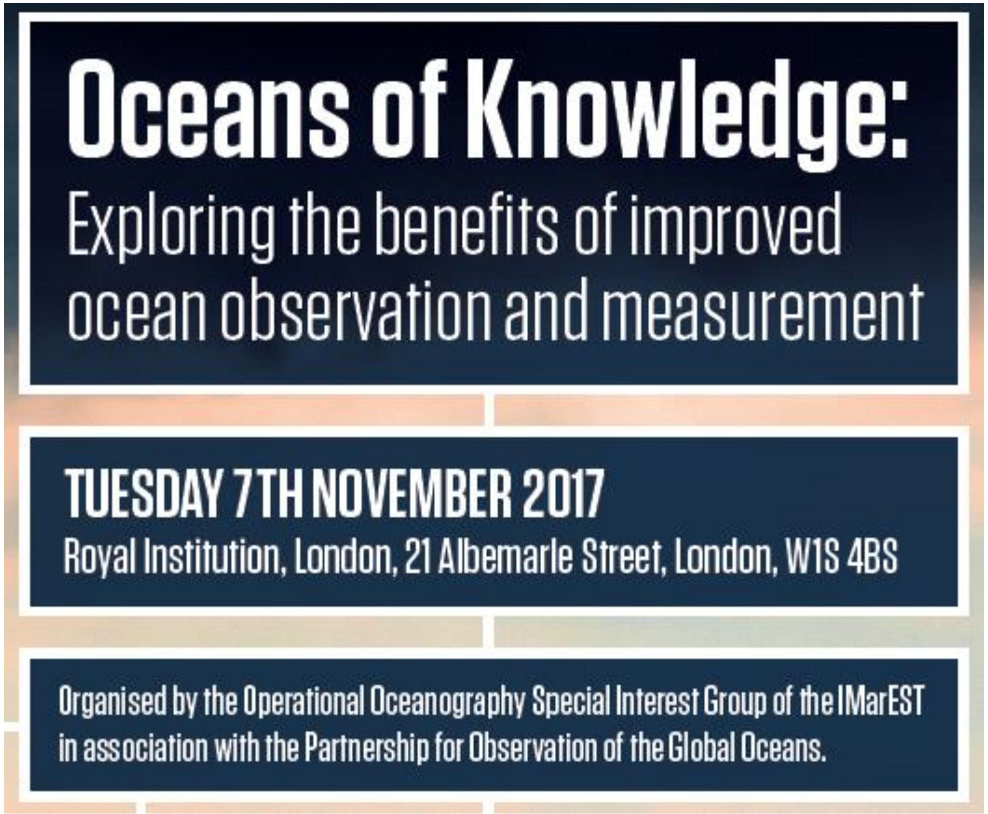
Ocean Passage Planning

Leisure Boats

Ship Emergency Response

Security of Navigation

2017 : User Benefits via Weather Forecasts



User Case Studies

Search & Rescue

Ship Routing

Aviation

Offshore Wind

Electrical Energy Distribution

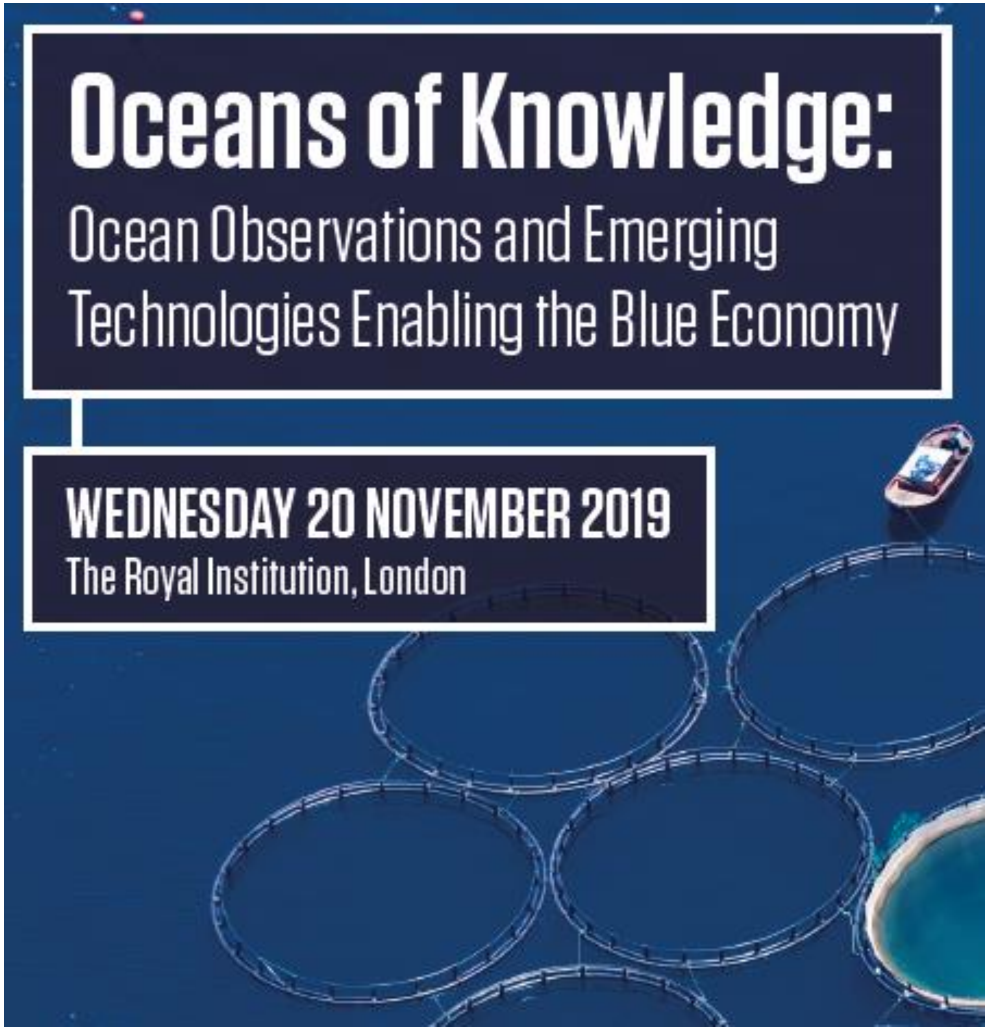
Aquaculture

Tropical Agriculture

Insurance & Reinsurance

Retail & Logistics

2019 : Enabling Growth of the Blue Economy



High Growth Uses

Autonomous Shipping

Open Water Aquaculture

Marine Mining

Offshore Wind

Enabling Technologies

Communication at Sea

Advanced Sensors

Earth Observation

Machine Learning

Robotics and Automation

2021 : Climate Change and the Ocean

Renewable Energy Transition

Challenges of rapid growth

Increasing demands of many users

Strategic ocean data requirements

Follow on workshop

COP26

2021 2030 United Nations Decade of Ocean Science for Sustainable Development
INSTITUTE OF MARINE Engineering, Science & Technology
SUT Society for Underwater Technology
LSE
Grantham Research Institute on Climate Change and the Environment
RMetS Royal Meteorological Society
IOP Institute of Physics
RISING SEAS

IOOS | Integrated Ocean Observing System

Benefits of Ocean Observations Catalog

Community developed   Community driven   Community benefit

Community Engagement

Building on work begun at OceanObs 19, the BOOC project aims to engage with the entire ocean observation, measurement, and modeling community.

Collecting Case Studies

The BOOC will be continuously updated with new use case studies that demonstrate the benefits of ocean observing worldwide.

Developing Standards

The BOOC will provide the community with access to a comprehensive, consistent, and constantly improving view of the benefits of ocean observing that can be easily searched by location, benefit area, and type of observation.

www.booc.info

https://ioos.noaa.gov/ioos-in-action/benefits-of-ocean-observing-catalog/