Emu Limited

OPENING THE WEATHER WINDOW – LESSONS LEARNT FROM THE OIL & GAS INDUSTRY

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Metocean data & decision making

Metocean data are crucial in decision making at all stages of all offshore developments:

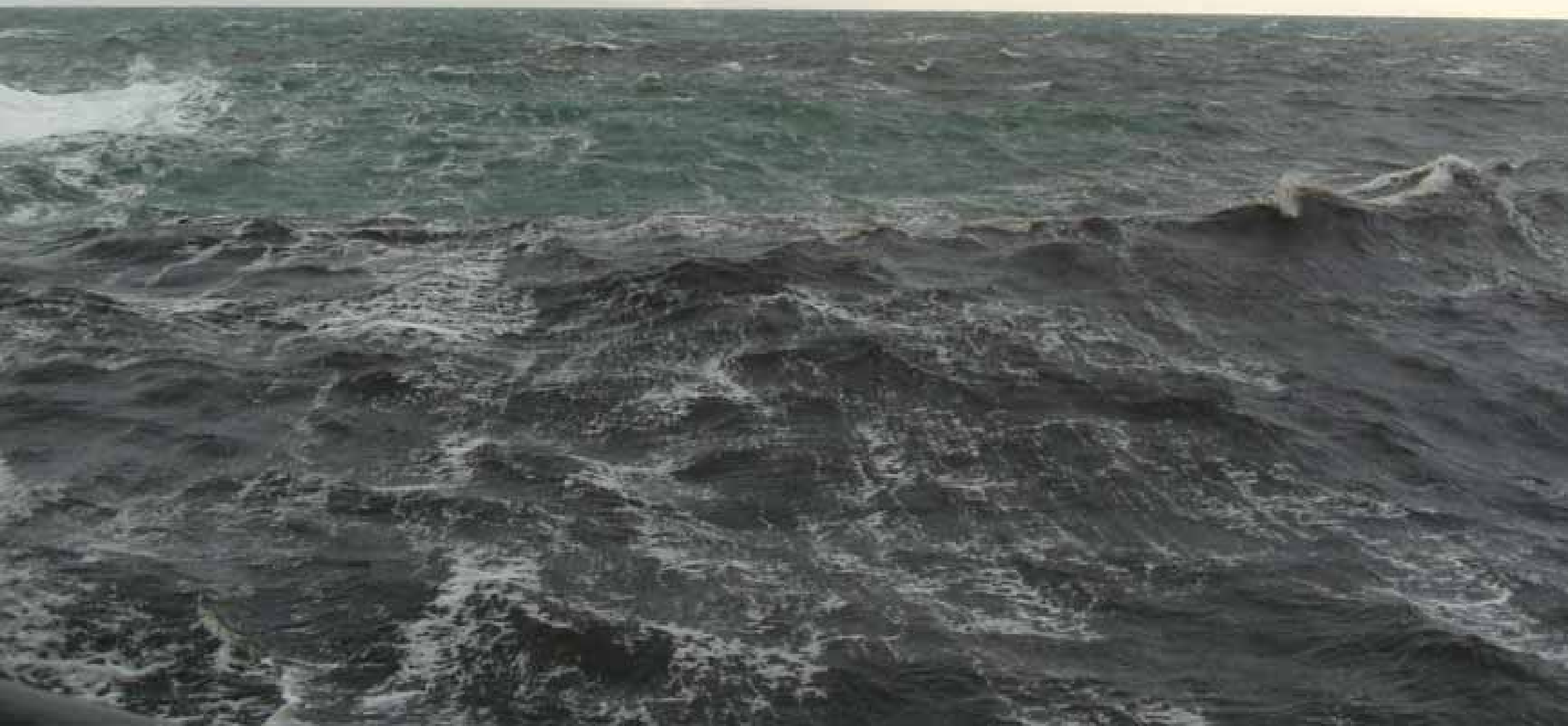
- Site selection
- Initial scoping
- Zonal and sub-zonal characterisation
- Environmental impact / coastal processes
- Design
- Construction
- Operations and maintenance

Working at sea – weather windows

Weather windows are elusive and hard to pin down.

- The question: Is it workable? Is not easily answered.
- The meteorological and oceanographic conditions at site are often complex and hard to predict accurately.
- Site specific weather forecasts are improving but when a decision is required and the forecast is inconclusive how do you decide?
- Do you always err on the side of caution?

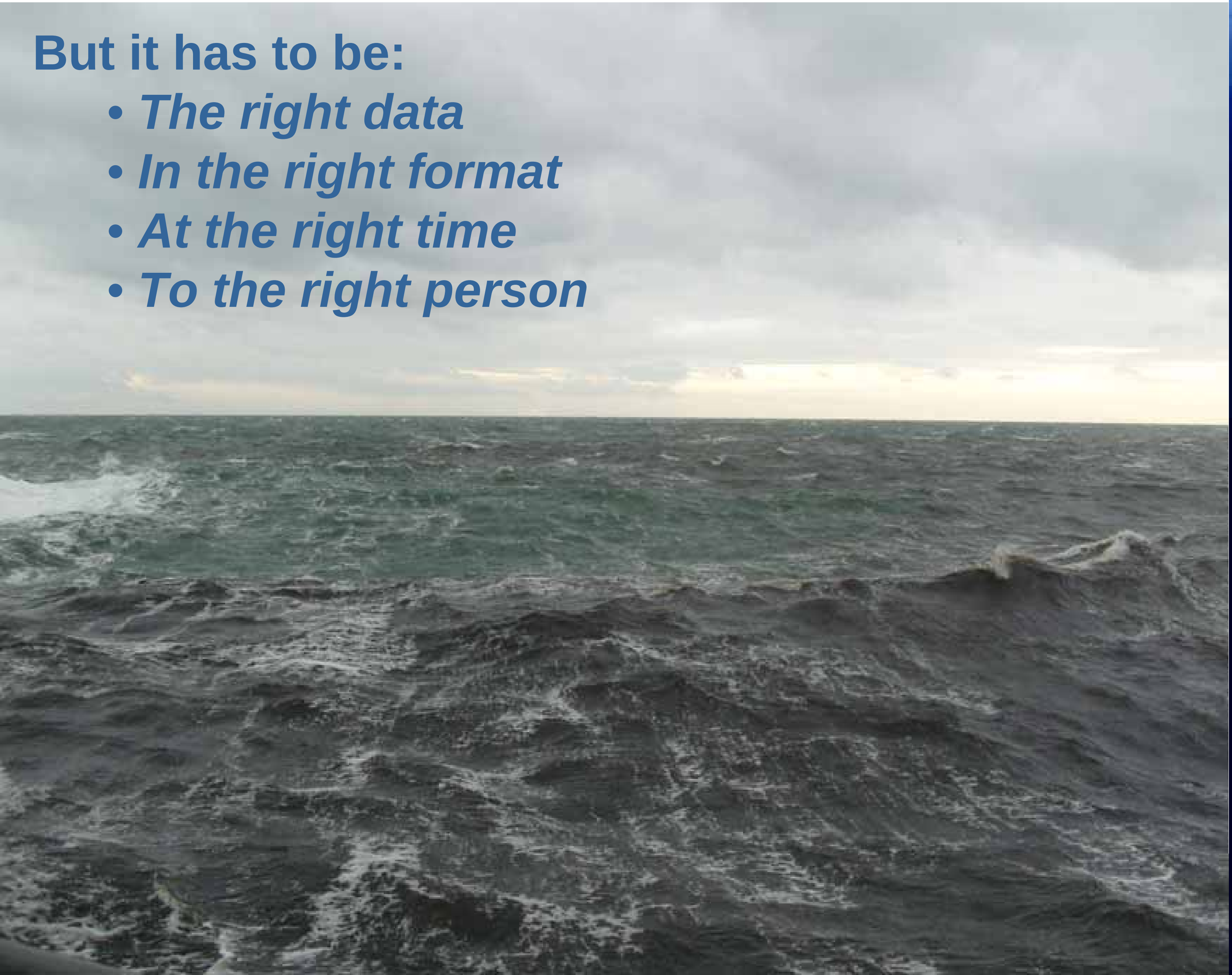
Real data can make a real difference.



Working at sea – weather windows

But it has to be:

- ***The right data***
- ***In the right format***
- ***At the right time***
- ***To the right person***



Oil & Gas installations offshore

The oil and gas industry have been installing structures offshore in the North Sea for nearly 40 years. Their experience should inform how the Renewable Energy industry moves into the next phase.

- Wave, tide, current and meteorological conditions directly affect operations.
- Wave data are particularly complex and will therefore be the focus for this talk.

An example project - North Sea

The client was attempting to collocate a Platform and a Jack Up Rig in the northern North Sea.

• Work delayed by 300 days as if swell predicted operations were halted.

• Required a system for monitoring sea conditions and separating waves by period in real time.

• Emu installed a wave rider buoy with 2 parallel receiver stations, with a bespoke web site.

• System installed and running within 7 days of initial approach.

• Work allowed to go ahead within 1 month of installation.

• Direct savings in excess of £2 million.

• Potential savings of in excess of £50 million.

Wave Measurement Devices:

Surface following buoys:

Advantages:

- Relatively simple to install,
- Telemetry via radio, GSM or satellite,
- Directional data.

Disadvantages:

- Require regular servicing,
- Moorings susceptible to damage,
- Buoys can go off station and can thus be lost.

Wave Measurement Devices:

Measurements from fixed structures:

Advantages:

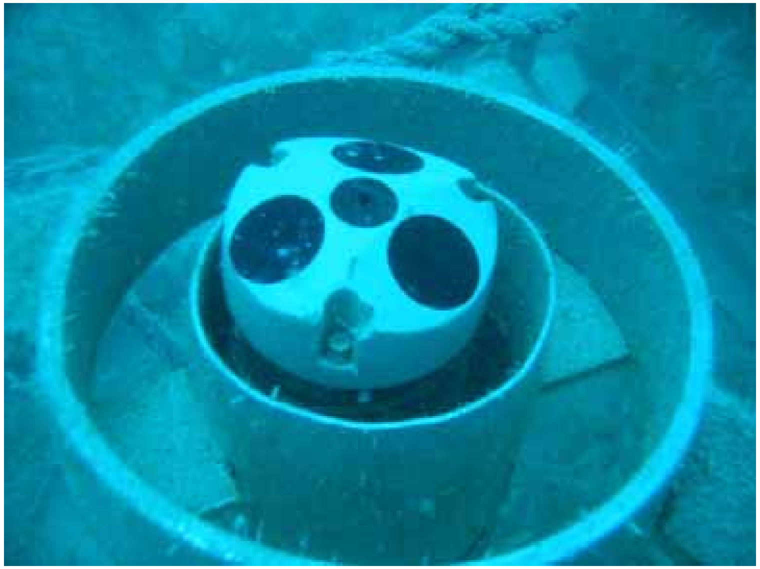
- Power from mains possible,
- Telemetry via cable, radio, GSM or satellite,
- Hard to lose.

Disadvantages:

- Non-directional,
- Interference from structure,
- Expensive to install.

Wave Measurement Devices:

Seabed mounted equipment:
Advantages:
- Simple to install,
- Additional parameters such as tide, current and suspended sediment,
- Can be invisible at surface.

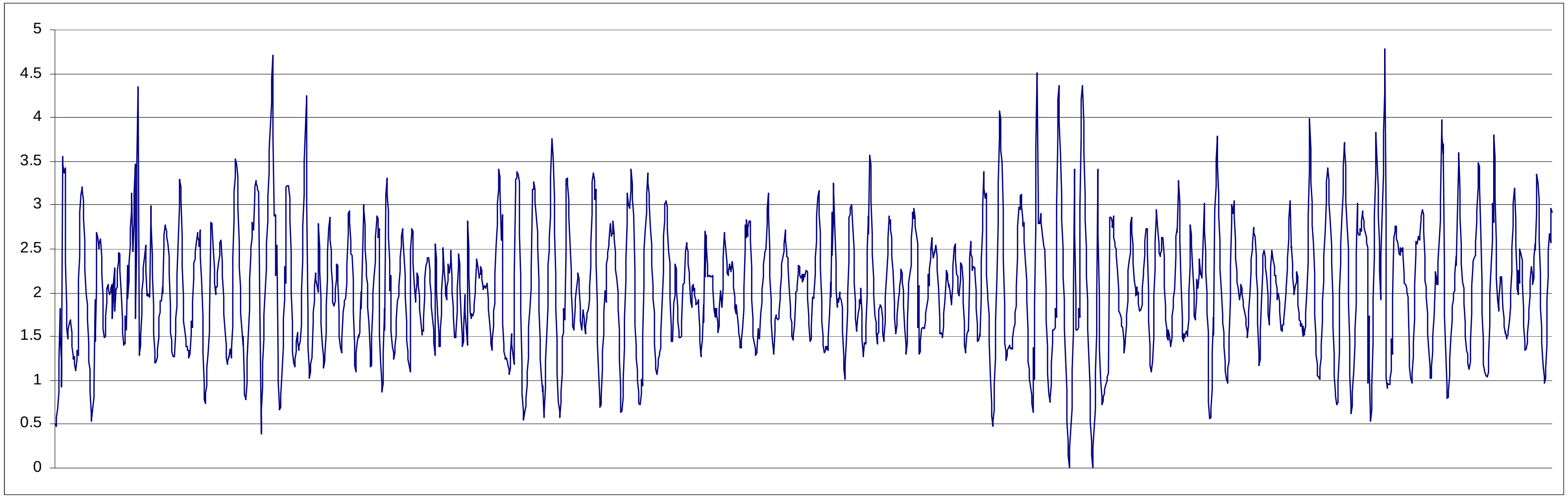


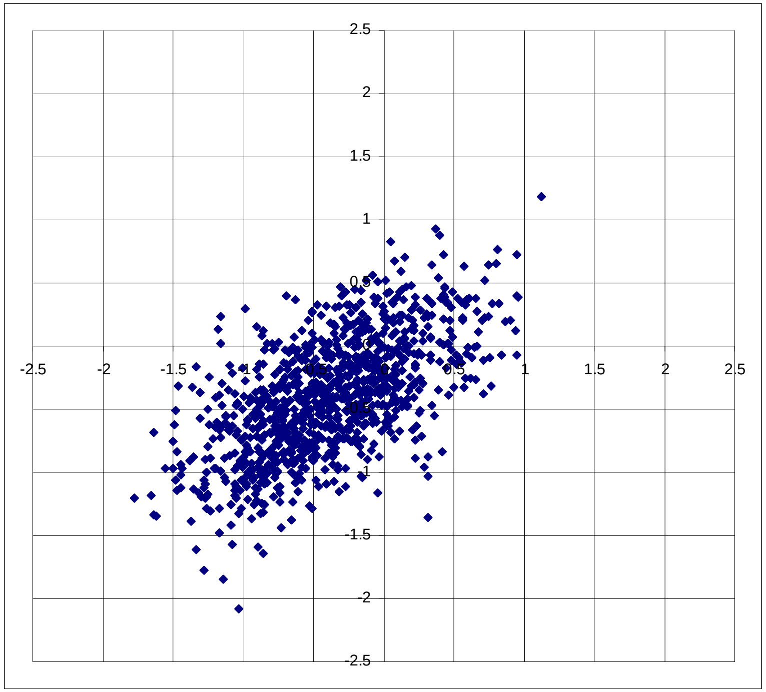
Disadvantages:
- Power either from battery packs or via cable,
- Require regular servicing,
- May need divers to recover,
- Can be susceptible to trawling.

Telemetry options to the surface:
- Cable from the seabed,
- Acoustic modems,
- Underwater radio modems.

All have potential problems.

What is measured?





All wave measurements are based on:

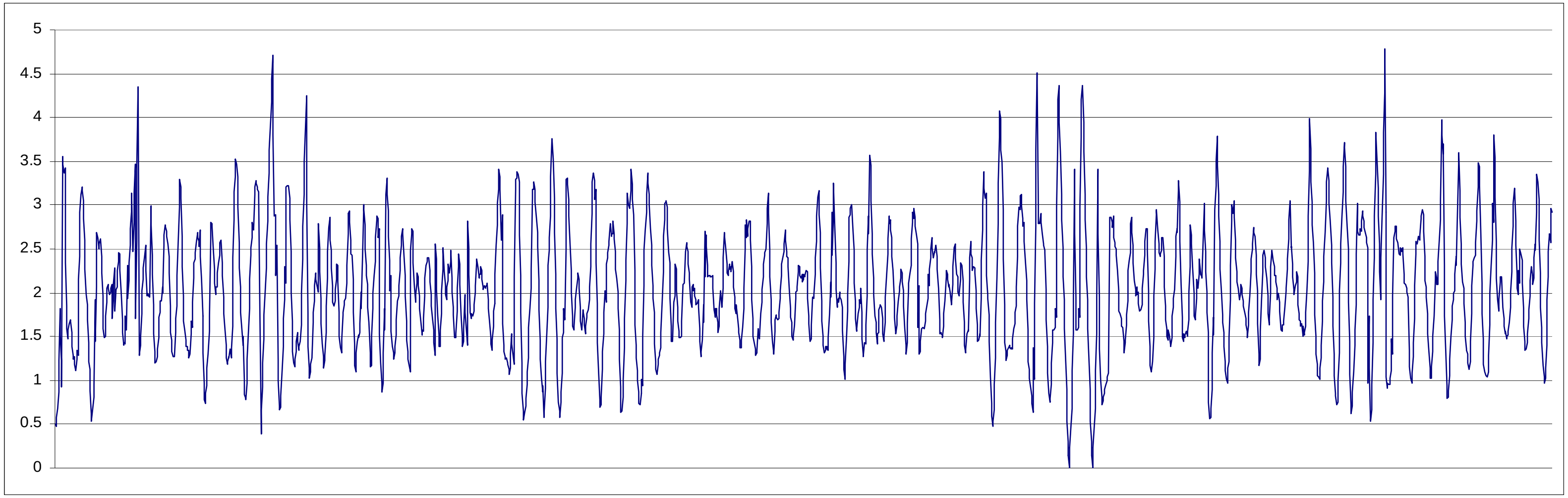
- A time series of surface elevations.
- Two sets of horizontal measurements either horizontal accelerations or horizontal current velocity measurements.

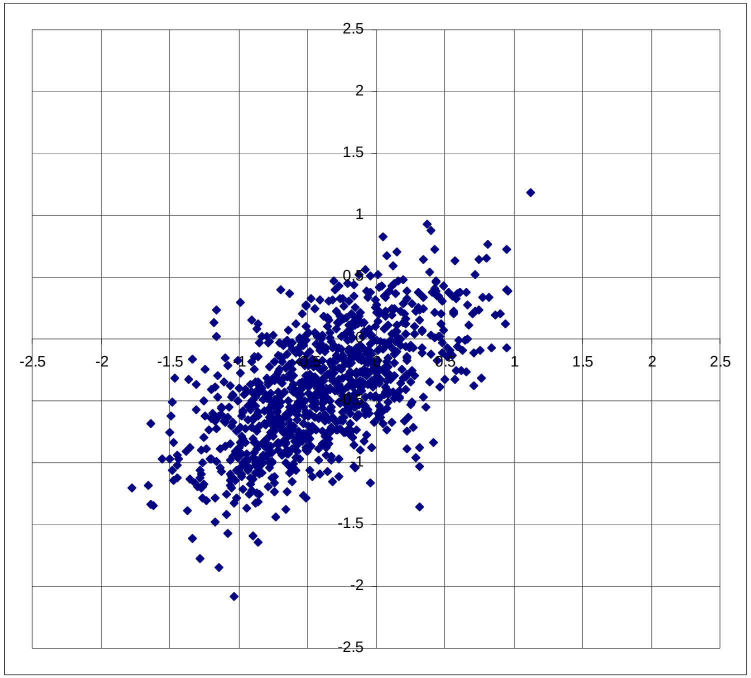
Everything else is a statistic!

What is reported?

Parameter Name	Abbreviation	Definition
Significant Wave Height	H_s	Any of: Mean of the largest third of the waves, 4 x Standard Deviation of the sea surface elevations, 4 x $M_0^{½}$ from the spectral analysis or wave height exceeded by 13.5% of all waves in a record.
Maximum Wave Height	H_{max}	Any of: The largest observed wave from trough to peak, the largest wave based on the probability of a single event of a pre defined period during the interval between records or a multiple of the significant wave height
1% Exceedence level	$H_{1\%}$	Wave height exceeded by 1% of all waves in a record
Spectral Moment	M_n	M_n = spectral moments vary from -5 to +5 usually, M_0 equivalent to the variance
Zero Up Crossing Period	T_z	The average period between waves cross the mean in an upward direction
Peak Period	T_p	Wave period corresponding to the spectral peak
Mean Period	T_m	Mean period of the waves, can be the burst length divided by the number of waves
Significant Period	T_s	Period associated with the significant wave height
Peak coming direction	D_p	Wave direction corresponding to spectral peak
Spreading	S_p	Directional spread corresponding to spectrum peak
Mean coming direction	D_m	Mean wave direction, various definitions
Total energy	E	Total energy in the wave burst
Spreading Factor	φ	Multiple used to reduce the in line current stresses to take account of directional spreading

But remember what is measured





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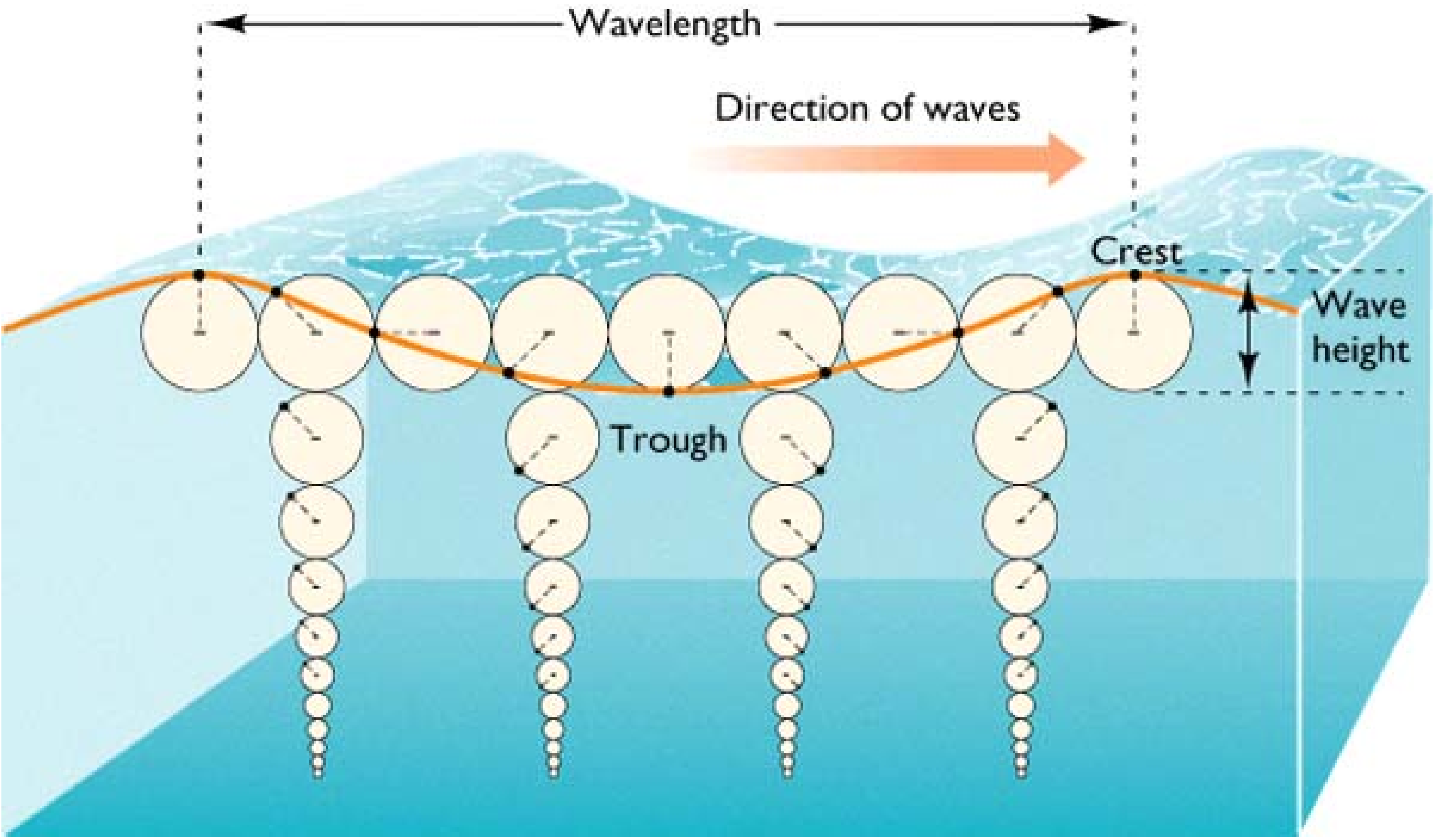
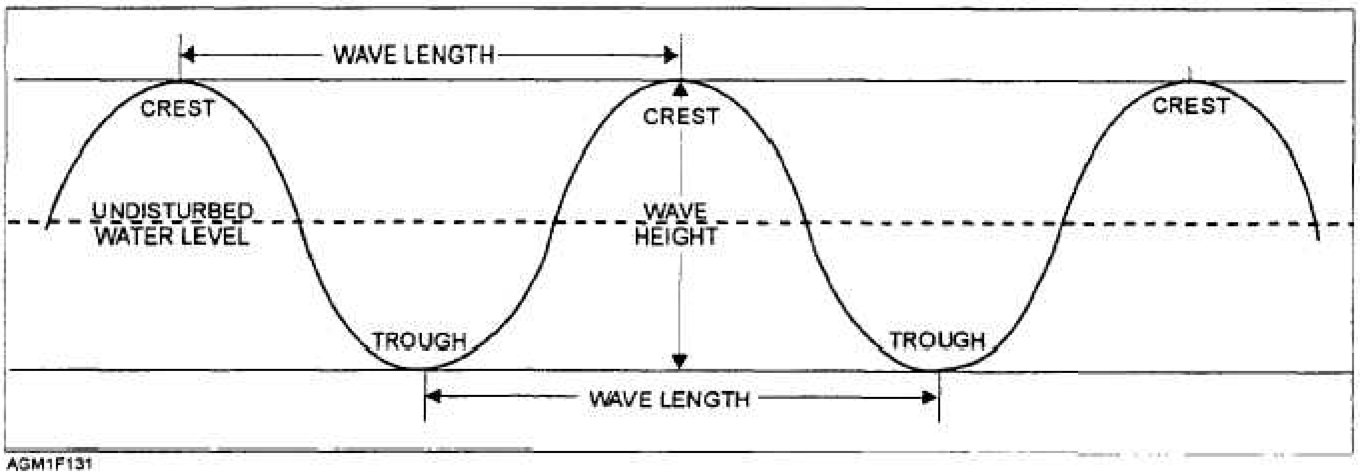
Theoretical wave motion



Theory versus reality



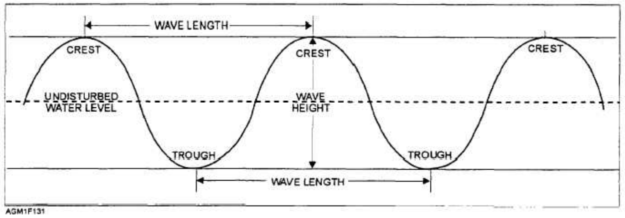
Theory based on sine waves, reality is random wave shapes.

Theory treats crests as continuous, reality is crests are short other than on beaches.

Wave processing approaches

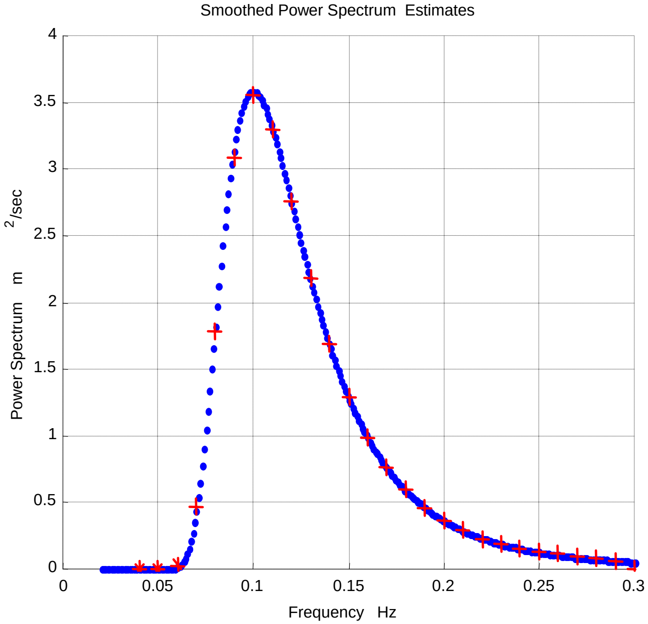
Deterministic processing:

- Parameters derived directly from the time series data for example significant wave height derived from the standard deviation of the surface elevations.
- Processing using deterministic approach produces values rapidly and simply.
- Very useful for a rapid updating automated system and for verifying spectrally derived parameters.



Spectral processing:

- The wave data are passed through a spectral analysis routine to divide the energy into differing periods (or frequencies).
- Industry standard approach based on Fourier Analysis.
- Highly versatile – can derive multitude of parameters.



Simplified wave processing

Wave processing is complex, to extract the required parameters can require pages of mathematical algorithms.

$$P_s = \left[\frac{\cosh kh}{\cosh k(h+z)}\right]^2 \frac{P_d}{\rho^2 g^2} \qquad k = \frac{2\pi}{L} \qquad c = \frac{L}{T} \qquad L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi}{L}\right) \qquad L_0 = \frac{gT^2}{2\pi} \qquad L = L_0 \tanh\left(\frac{2\pi}{L}\right) \qquad m_n = \sum\left[f^i E(f_i)\Delta f_i\right]$$

$$\theta_f = \arctan 2\left(a_1^{\,2} + b_1^{\,2}\right) \qquad a_1 = \frac{C_{zu}}{\sqrt{C_{zz}(C_{uu}+C_{vv})}} \qquad b_1 = \frac{C_{zv}}{\sqrt{C_{zz}(C_{uu}+C_{vv})}}$$

$$C_{zz} = \alpha_{zf}^{\,2} + \beta_{zf}^{\,2} \qquad C_{vz} = \alpha_{vf}\beta_{zf} - \beta_{vf}\alpha_{zf}$$

$$\mathrm{D}(\mathrm{f},\theta) = \frac{1}{\pi}\left(\frac{1}{2} + a_1\cos\theta + b_1\sin\theta + a_2\cos 2\theta + b_2\sin 2\theta\right)$$

$$a_2 = \frac{C_{uu} - C_{zz}}{C_{uu} + C_{zz}} \qquad b_2 = \frac{-2C_{zv}}{C_{zz} + C_{vv}}$$

Luckily this is our problem not yours!

To make data available online extensive processing via robust proven systems is a requirement, the data must be RIGHT.

Spectral Processing

The Maths:

Wave data broken down into Fourier series in 3 dimensions:

$$\eta(x, y, t) = \sum_{m=1} \sum_{n=1} A_{mn} \cos\psi_{mn}(x, y, t)$$

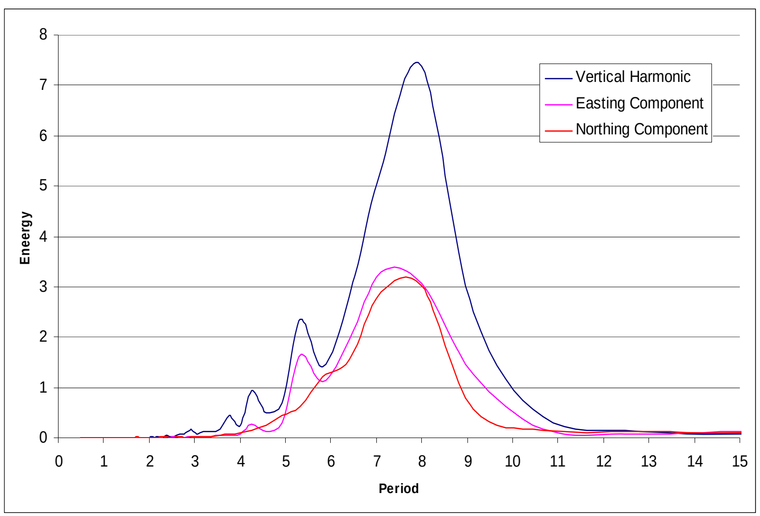
Vertical component

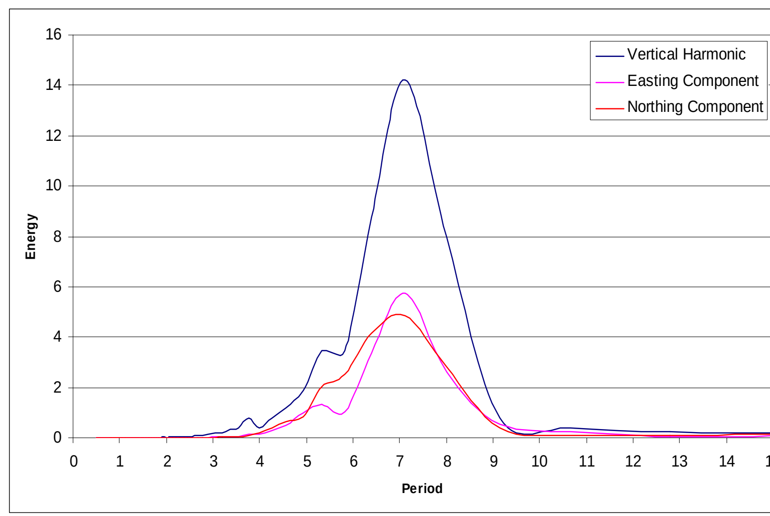
$$u(x, y, z, t) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} Q_m(z) \cos\theta_n \cos\psi_{mn}(x, y, t)$$

First horizontal component

$$v(x, y, z, t) = \sum_{m=1} \sum_{n=1} A_{mn} Q_m(z) \sin\theta_n \cos\psi_{mn}(x, y, t)$$

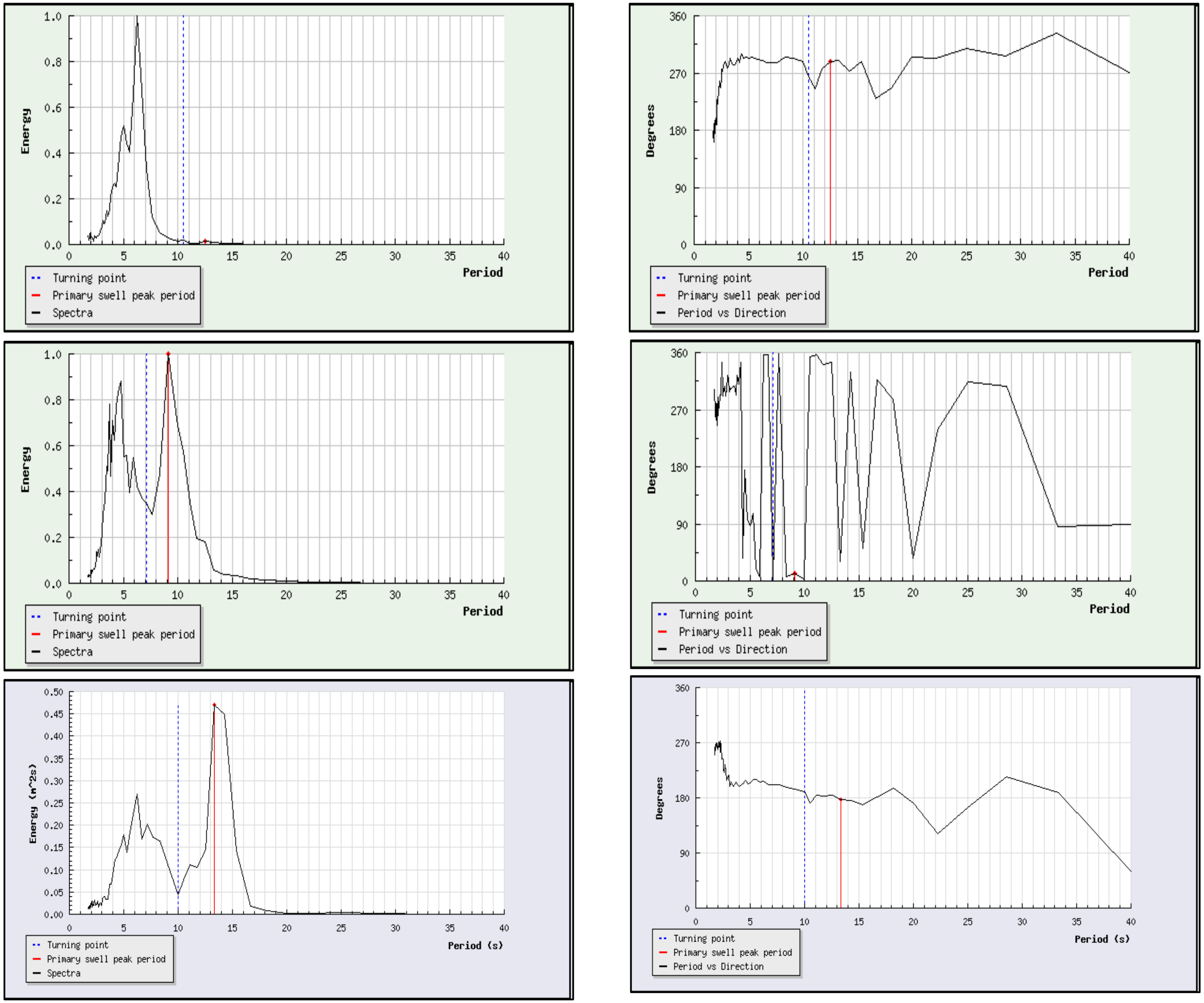
Second horizontal component





Understanding the wave spectra can save money and reduce risk. Vessels have been damaged due to the wave periodicity.

Example spectra



This system is now being used throughout the South of England for coastal defence as well as by Offshore Wind Farm developers.

2 D wave spectra

Client

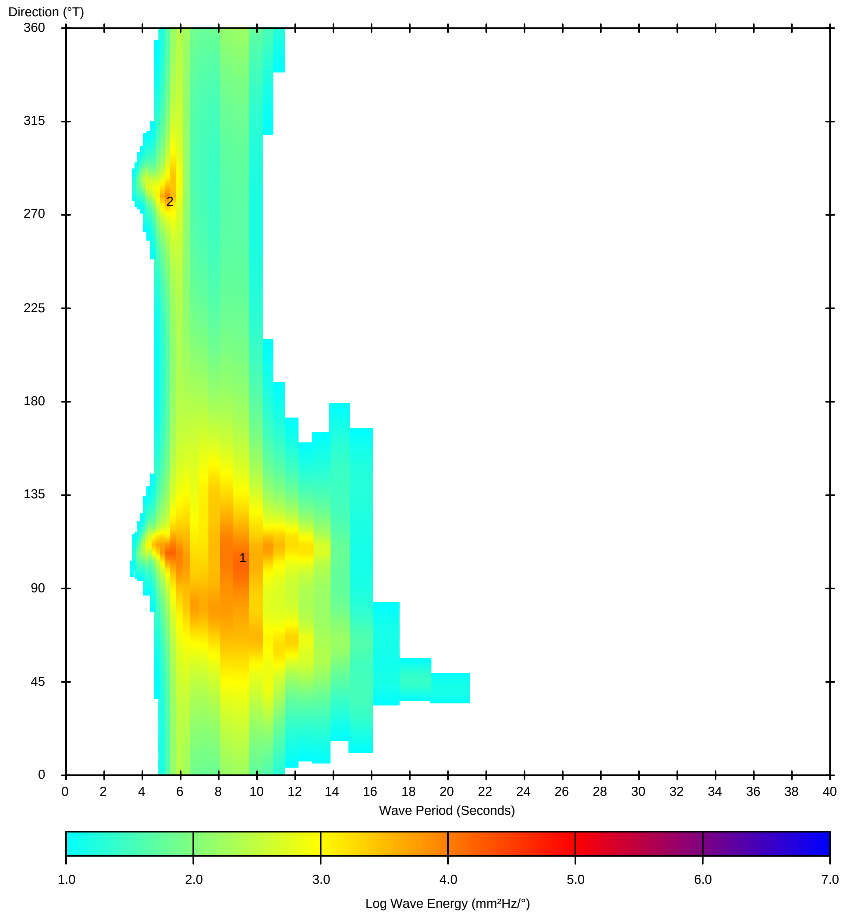
Directional Wave Spectral Analysis
Job Name

Figure 3801

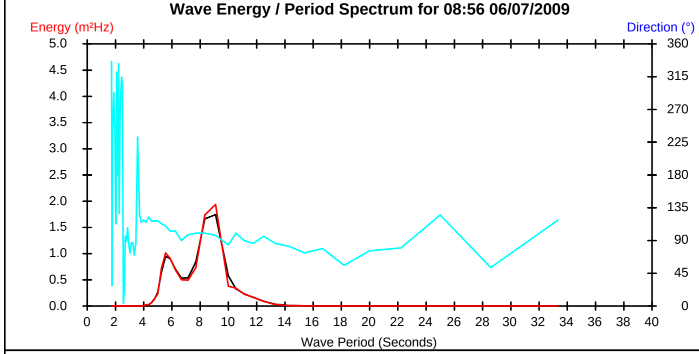
Position: Latitude: XX° XX.XXX' N, Longitude: XXX° XX.XXX' W Site Depth: 100m
Deployed: 05:25 19/04/2009, Recovered 06/08/2009

Datawell DWR MkIII
Serial No.: 30554

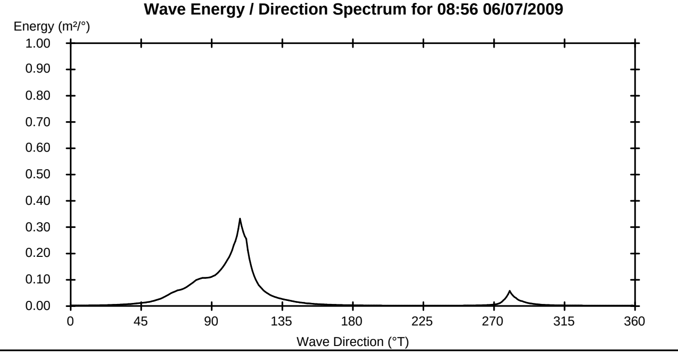
Two Dimensional Wave Energy Spectrum for 08:56 06/07/2009



Wave Energy / Period Spectrum for 08:56 06/07/2009



Wave Energy / Direction Spectrum for 08:56 06/07/2009



Wave Statistics for 08:56 06/07/2009

Zeroth Spectral Moment:	0.052m²	Peak Period:	9.1s
Significant Wave Height:	0.92m	Zero Up Crossing Period:	6.8s
Maximum Wave Height:	1.25m	Mean Coming Direction (°T):	76.8°
		Peak Coming Direction (°T):	97.0°
		Directional - Peak Direction (°T):	108.0°

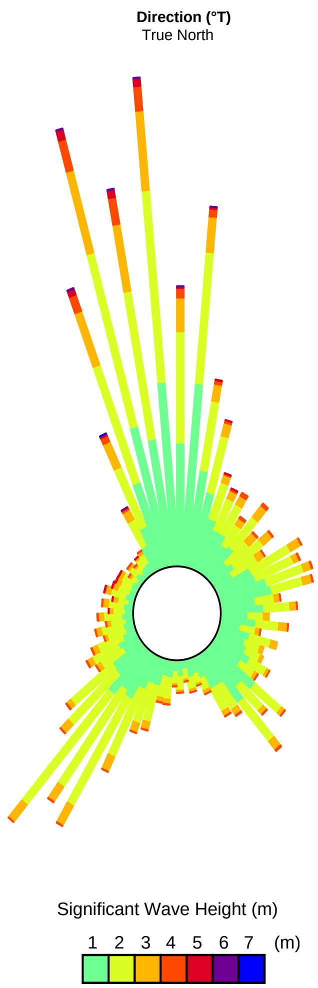
Primary Zeroth Spectral Moment:	0.048m²
Primary Significant Wave Height:	0.88m
Primary Peak Period:	9.1s
Primary Peak Direction:	108°
Secondary Zeroth Spectral Moment:	0.003m²
Secondary Significant Wave Height:	0.23m
Secondary Peak Period:	5.3s
Secondary Peak Direction:	280°

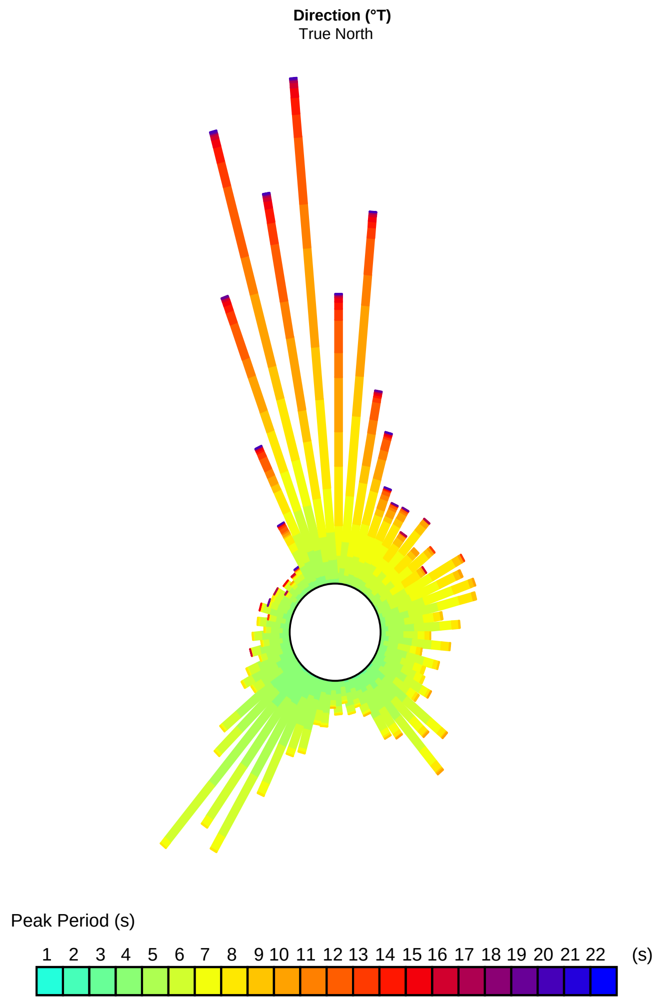
Emu Limited Oceanographic Section

Job No: J/1/01/XXXX

Understanding the short period wave direction saved a developer approximately £2 million in construction costs.

Wave height, period and direction

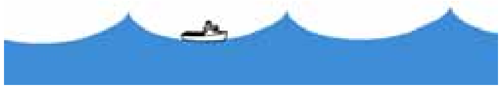




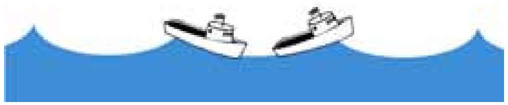
Understanding the complexities of your site can save money, save time and reduce risk.

What does it all mean?

Observed local wave conditions at any site = More than one wave train



Therefore the wave statistics describing the overall wave climate may not give the full picture.



Splitting the wave spectrum into its "sea" and "swell" components highlights the proportion of energy attributable to the most damaging types of waves.

Assists in:

- Design criteria
- Health and safety
- Planning and logistical support
- Forecasting

Examples of the parameters which may be derived include:

- Total/Swell/Wind Zeroeth Spectral Moments
- Primary Swell/Wind Significant Wave Height
- Primary Swell/Wind Peak Period
- Primary Swell/Wind Peak Period Direction

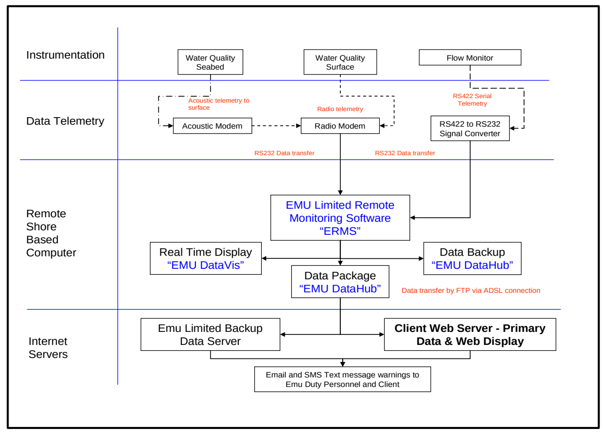
Making the data work

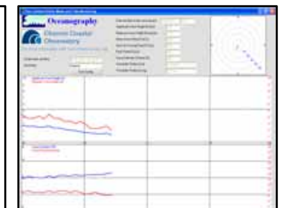
Oceanographic and meteorological Instrumentation must be:

- Installed properly,
- Serviced regularly,
- Supported,
- Understood.

Emu's bespoke software:

- Collation,
- Processing,
- Quality control,
- Interpretation,
- Presentation,
- Dissemination.



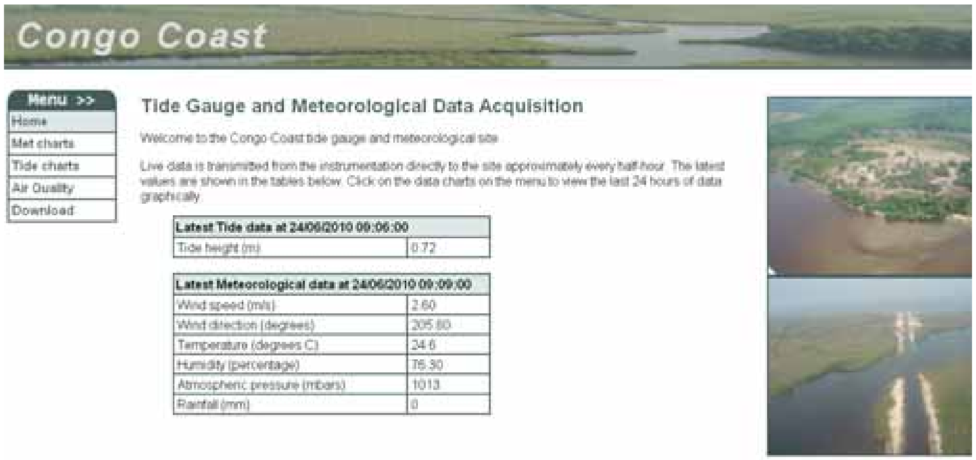


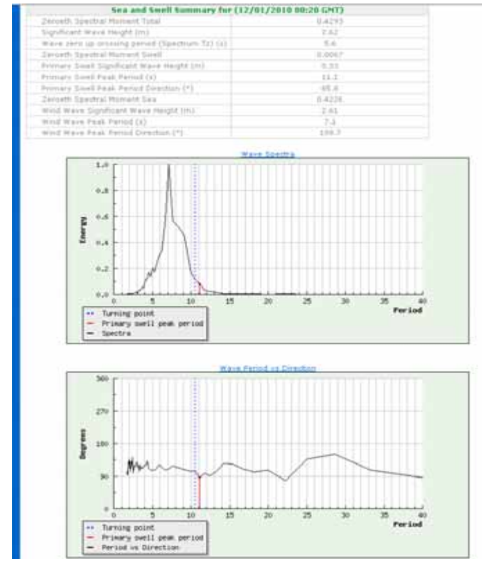
Client focused data interaction:

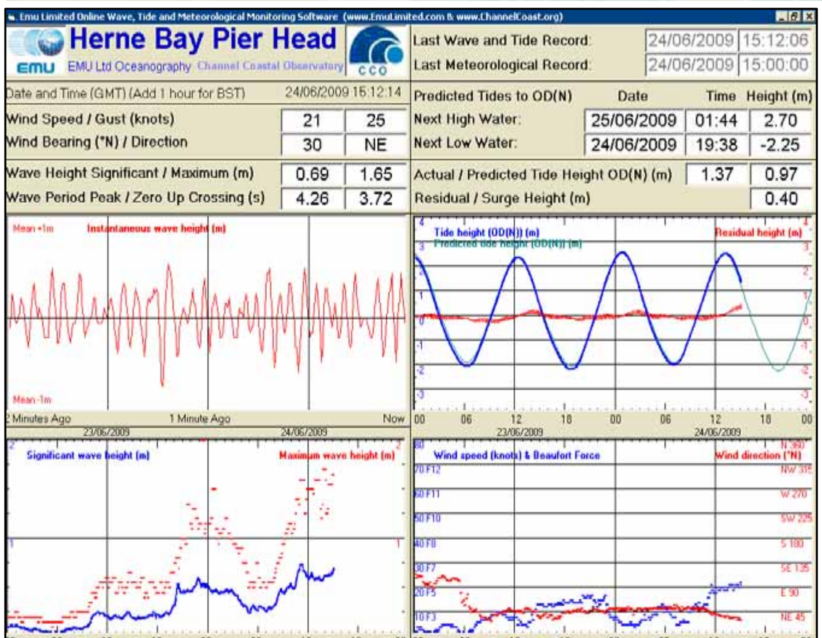
- Tables,
- Graphs,
- Statistics,
- Spectra,
- Maps,
- Whatever is needed!

Data display & interaction

Metocean data interfaces design to client centric.







Time (GMT)	Latitude	Longitude	Wave Height (m)	Max Wave Height (m)	Tpeak (s)	Tz (s)	Mean Direction (degrees)	Spread (degrees)	Sea Temp (°C)
24-06-2010 08:00	51.24960	1.48275	0.22	0.56	5	2.9	110	40	14.9
24-06-2010 07:30	51.24954	1.48283	0.2	0.4	2.9	3	173	55	15
24-06-2010 07:00	51.24948	1.48290	0.21	0.31	4.6	3.1	166	41	14.8
24-06-2010 06:30	51.24950	1.48288	0.2	0.31	3.1	3.1	197	44	14.4
24-06-2010 06:00	51.24946	1.48290	0.2	0.25	3.2	3	169	40	14.5
24-06-2010 05:30	51.24945	1.48294	0.23	0.28	3.1	3.1	188	54	14.5
24-06-2010 05:00	51.24947	1.48296	0.21	0.34	2.8	2.9	193	47	14.5
24-06-2010 04:30	51.24948	1.48296	0.2	0.43	2.9	2.8	180	42	14.5
24-06-2010 04:00	51.24951	1.48303	0.23	0.32	4	3	172	27	14.5
24-06-2010 03:30	51.24954	1.48313	0.21	0.34	4.8	2.9	159	31	14.4
24-06-2010 03:00	51.24992	1.48371	0.2	0.32	3.2	2.7	162	33	14.4
24-06-2010 02:30	51.25020	1.48360	0.19	0.28	3.3	2.9	167	42	14.4
24-06-2010 02:00	51.25028	1.48354	0.18	0.27	3.3	3.2	158	42	14.4
24-06-2010 01:30	51.25031	1.48354	0.17	0.27	4.4	3.3	135	57	14.4
24-06-2010 01:00	51.25033	1.48354	0.18	0.26	5	3.4	80	50	14.4
24-06-2010 00:30	51.25036	1.48348	0.18	0.25	5.6	3.3	100	54	14.4
24-06-2010 00:00	51.25035	1.48352	0.19	0.29	3.5	3.3	143	53	14.5
23-06-2010 23:30	51.25043	1.48352	0.2	0.29	4.8	3.2	158	68	14.6
23-06-2010 23:00	51.25039	1.48350	0.21	0.34	4.2	3.2	163	52	14.5
23-06-2010 22:30	51.25045	1.48345	0.22	0.3	4.8	3.2	167	67	14.4
23-06-2010 22:00	51.25044	1.48343	0.25	0.3	5.3	2.9	173	49	14.4
23-06-2010 21:30	51.25044	1.48337	0.25	0.35	5.3	2.9	91	54	14.5

Latest Sea and Swell Summary (12/01/2010 00:20 GMT)	
Primary Swell Significant Wave Height (m)	0
Primary Swell Peak Period (s)	0
Wind Wave Significant Wave Height (m)	2.63
Wind Wave Peak Period (s)	7.1

EMU

Real-time 24 hours monitoring

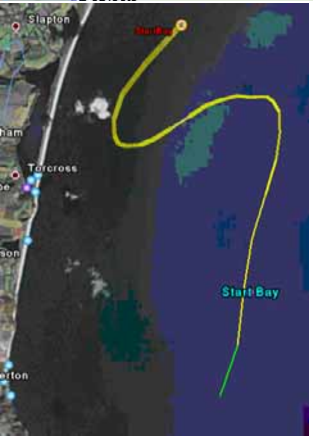
Real time Quality Control monitoring is essential.

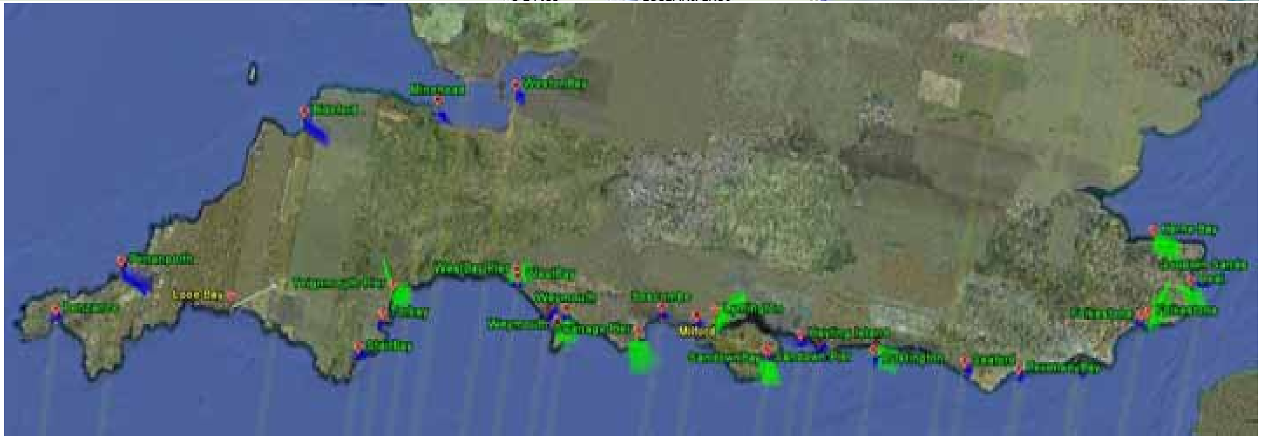
09/06/09 13:35

Refresh

13:35:22

		W Recs	Lat	Long	Hs	Hmax	Tp	Tz	Mean	Sprd	Sea Temj	Excm	Time	Tide	Resid	T Recs	Time	M Recs	Air Pr	Wind Knt	Wind ms	Gust Knt:	Gust ms	Dir	Air T
Rhyl Flats	09/06/09 12:00	47/48	53.38173	-3.60068	0.62	0.90	04.4	-	003	20	13.0	66	-	-	-	-	12:50	141/144	-	-	8.1	-	8.7	009	10.1
Gwynt y Mor	09/06/09 12:00	47/48	53.47999	-3.57174	0.68	1.05	04.2	-	017	24	12.2	129	-	-	-	-	12:50	141/144	-	-	7.6	-	0.2	006	12.2
Minehead	09/06/09 12:30	48/48	51.22727	-3.47003	0.30	0.37	02.6	2.5	028	38	15.1	166	-	-	-	-	-	-	-	-	-	-	-	-	-
Perranporth	09/06/09 12:30	48/48	50.35273	-5.17510	0.56	0.82	11.1	4.0	278	22	13.2	108	-	-	-	-	-	-	-	-	-	-	-	-	-
Penzance	09/06/09 12:30	48/48	50.11460	-5.50349	0.98	1.49	10.0	6.0	186	11	13.3	60	-	-	-	-	-	-	-	-	-	-	-	-	-
Start Bay	09/06/09 12:30	48/48	50.29205	-3.61618	0.98	1.28	11.8	5.3	173	44	14.2	100	-	-	-	-	-	-	-	-	-	-	-	-	-
Torbay	09/06/09 12:30	48/48	50.43303	-3.51841	0.55	0.85	05.6	3.8	108	21	14.6	93	-	-	-	-	-	-	-	-	-	-	-	-	-
eignmouth Pier	09/06/09 13:21	145/144	-	-	0.43	1.69	12.5	4.4	-	-	-	-	13:21	1.57	-0.04	144/144	13:20	144/144	1006	7.3	3.6	10.0	5.0	020	0.0
West Bay	09/06/09 12:30	48/48	50.69298	-2.75002	0.99	1.52	11.8	9.5	214	24	14.5	78	-	-	-	-	-	-	-	-	-	-	-	-	-
West Bay Pier	09/06/09 13:20	113/144	-	-	0.00	0.00	00.0	0.0	-	-	-	-	13:20	1.36	-	112/144	13:20	249/144	1007	5.9	3.0	9.2	4.6	360	15.0
Chesil	09/06/09 12:30	48/48	50.60246	-2.52368	0.75	1.80	12.5	8.5	219	39	13.8	113	-	-	-	-	-	-	-	-	-	-	-	-	-
Weymouth	09/06/09 12:30	48/48	50.62265	-2.41382	0.37	0.71	11.8	4.7	162	22	14.1	46	-	-	-	-	13:11	143/144	1007	5.9	2.9	6.8	3.4	070	-65.2
Swanage Pier	09/06/09 13:11	144/144	-	-	0.32	1.07	09.0	3.5	-	-	-	-	13:11	1.99	-	143/144	13:11	143/144	1007	8.4	4.2	8.9	4.5	360	14.8
Boscombe	09/06/09 12:30	48/48	50.71139	-1.83976	0.37	0.58	05.6	4.3	149	18	15.7	50	-	-	-	-	-	-	-	-	-	-	-	-	-
Milford	09/06/09 12:30	48/48	50.71214	-1.61468	0.29	0.39	13.3	4.8	187	55	15.2	62	-	-	-	-	-	-	-	-	-	-	-	-	-
Lymington	09/06/09 13:20	144/72	-	-	0.06	0.20	02.6	2.2	-	-	-	-	13:20	3.03	-	143/144	13:18	154/144	1006	12.0	6.0	15.6	7.8	340	0.0
Sandown Bay	09/06/09 12:30	48/48	50.65104	-1.13187	0.58	0.91	04.8	3.8	118	22	14.8	74	-	-	-	-	-	-	-	-	-	-	-	-	-
Sandown Pier	09/06/09 13:21	145/144	-	-	0.36	1.09	09.2	3.7	-	-	-	-	13:21	4.21	0.15	144/144	13:21	144/144	1004	8.2	4.1	10.2	5.1	350	15.2
Hayling Island	09/06/09 12:30	48/48	50.73218	-0.95933	0.43	0.48	04.2	2.9	155	34	15.3	69	-	-	-	-	-	-	-	-	-	-	-	-	-
Bracklesham	09/06/09 12:30	48/48	50.72315	-0.83764	0.36	0.60	12.5	2.9	210	42	15.5	111	-	-	-	-	-	-	-	-	-	-	-	-	-
Rustington	09/06/09 12:30	48/48	50.73406	-0.49563	0.50	0.60	03.2	2.6	091	22	15.4	78	-	-	-	-	-	-	-	-	-	-	-	-	-
Arun Platform	-	-	-	-	-	-	-	-	-	-	-	-	13:16	5.31	-	139/144	13:16	8/144	1004	14.6	7.3	0.0	0.0	010	14.0
Pevensey Bay	09/06/09 12:30	48/48	50.78292	0.41658	0.42	0.56	04.4	2.7	077	21	15.3	55	-	-	-	-	-	-	-	-	-	-	-	-	-
Seaford	09/06/09 12:30	48/48	50.76603	0.07506	0.20	0.24	02.9	2.7	136	38	15.0	87	-	-	-	-	-	-	-	-	-	-	-	-	-
Rye	09/06/09 12:30	48/48	50.85180	0.79054	0.28	0.39	04.4	3.0	089	22	14.0	121	-	-	-	-	-	-	-	-	-	-	-	-	-
Folkestone	09/06/09 12:30	48/48	51.06258	1.12900	0.33	0.53	05.6	3.8	090	21	14.4	99	-	-	-	-	13:10	143/144	0996	21.1	10.6	28.3	14.2	040	-
Deal	09/06/09 13:21	145/144	-	-	0.39	0.91	06.3	3.7	-	-	-	-	13:21	5.65	0.12	144/144	13:21	144/144	1005	9.8	4.9	10.8	5.4	010	16.8
Goodwin Sands	09/06/09 12:30	48/48	51.25047	1.48343	0.55	0.81	05.3	4.0	048	46	14.3	132	-	-	-	-	-	-	-	-	-	-	-	-	-
Herne Bay	09/06/09 13:20	144/144	-	-	0.24	0.50	04.4	2.9	-	-	-	-	13:20	5.09	0.12	143/144	13:10	142/144	0000	7.6	3.8	9.5	4.7	030	0.0
Hornsea	09/06/09 12:30	48/48	53.91709	-0.06712	0.93	1.68	05.0	3.7	046	25	12.2	109	-	-	-	-	-	-	-	-	-	-	-	-	-
Buzzard	09/06/09 12:30	48/48	57.81695	-0.97667	0.94	1.33	07.1	4.1	016	18	-5.0	396	-	-	-	-	-	-	-	-	-	-	-	-	-
Angola	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Angola	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-





So what have we learnt?

It is vital to understand your environment, from all angles.
If suppliers and developers work in partnership better results are achieved.
Make certain the data answers the question, client focused development.
Metocean data is complex and easily misunderstood, seek advice.
Real data can make a real difference.

Make certain it is the:

- ***The right data*** – the data answers the questions being asked,
- ***In the right format*** – present the data in an appropriate way,
- ***At the right time*** – deliver the data in a time frame that supports the decisions,
- ***To the right person*** – data must be available to decision makers at all times.

EMU

Thank you for your time.

Emu Limited

OPENING THE WEATHER WINDOW – LESSONS LEARNT FROM THE OIL & GAS INDUSTRY

Robin Newman, Principal MetOcean Scientist Emu Limited