Design Considerations Offshore West Africa

Part II

Town and Gown
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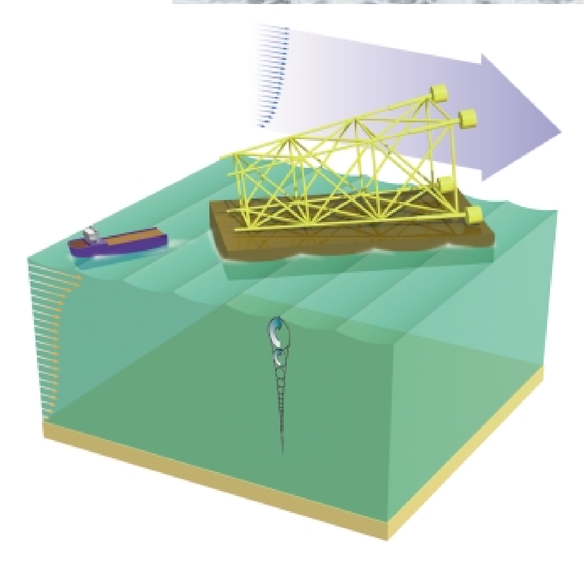

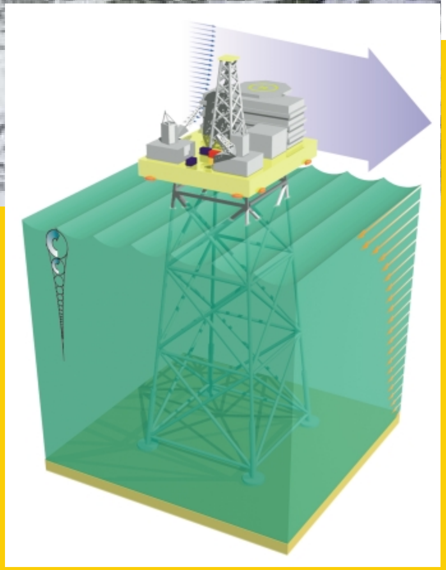

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Directional Metocean Extremes and Failure Modes

- Turbulence:
- Oceanic turbulence
- Atmospheric turbulence

For fully developed turbulence, the velocity fluctuates over a large range of coupled spatial and temporal scales.

$$u(t) = \bar{u} + u'(t)$$

Stream velocity

Mean velocity

Turbulent fluctuation

Directional Metocean Extremes and Failure Modes

- Between 2001 and 2011, there were 21 mooring failures—an average of more than two per year (Kai-Tung Ma ,OTC.13, paper OTC- 24025-MS). Nine were multiple-line failures.
- 23 permanent mooring failures since 2000, and four of those were categorized as catastrophic, with riser failure and extended field shut-down. (Granherne , OTC.13, OTC-24181),
- 20 floating production systems (FPS) had integrity issues requiring intervention and 150 mooring lines were repaired or replaced across 33 FPS (Sai Majh, of Granherne)

North Sea: multiple mooring line failures incidences

Year	Name	Type	Cause	No. Lines Broken
1981	North Sea Pioneer	Semi-sub (FPF)	Large waves and strong winds	ALL
1994	Petrojarl 1	FPSO	Large waves and strong winds	4 of 8
2004	Ocean Vanguarg	Semi-sub (drilling)	Large waves and strong winds	2 of 8
2011	Gryphon	FPSO	Heading control power loss	4 of 10

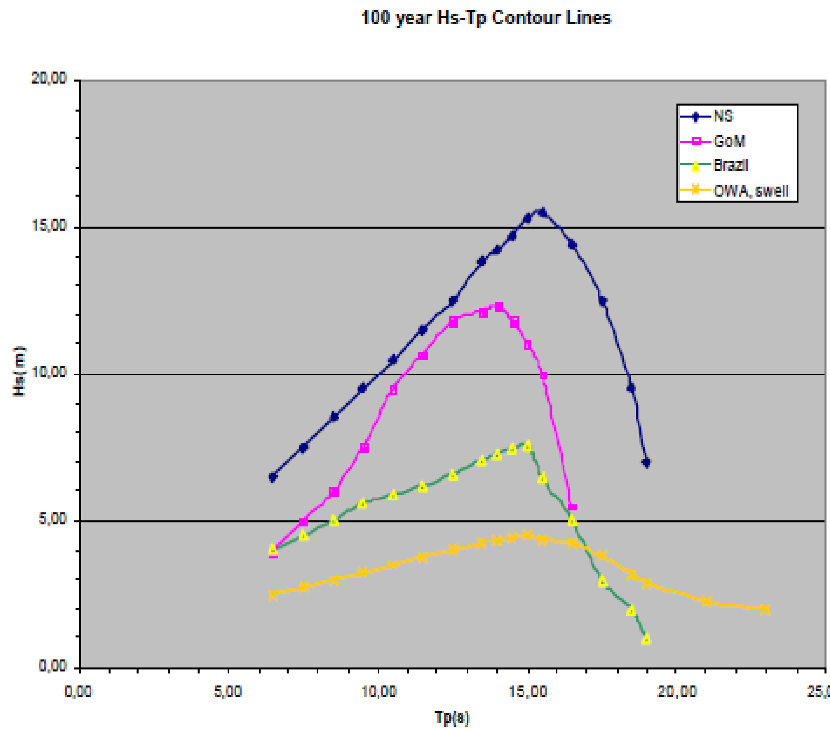
Ref.: Implications of Potential Mooring Regulation Change on UKCS Installations Carolyne Claxton, 22/11/2013

…..cost an estimated US$1.8billion to reinstate

It’s important therefore to ensure that design methodology assumptions are correct, reflecting worse-case scenarios.

Directional Metocean Extremes and Failure Modes

- **Wave:**
- Swell: Persistent long-period swells from the SSW v
uncorrelated low-intensity wind and current;
- Sea: Generated by SW locally monsoon wind
- Current: High-surface current
- **Wind:**
- Moonsoon wind
- Squalls that are short duration (typically one hour) a
very high wind speeds (5sec gust greater than 30
m/s);
  - Squalls typically originate over land and propagate over the ocean, but locally can be incident from almost any direction
  - Squalls are difficult to forecast accurately and varies in intensity and direction



Directional Metocean Extremes and Failure Modes

- A current design methodology
  - Constant wind speed approach
  - Does not give a good level of confidence in the conservatism achieved
  - Factor of safety is unclear

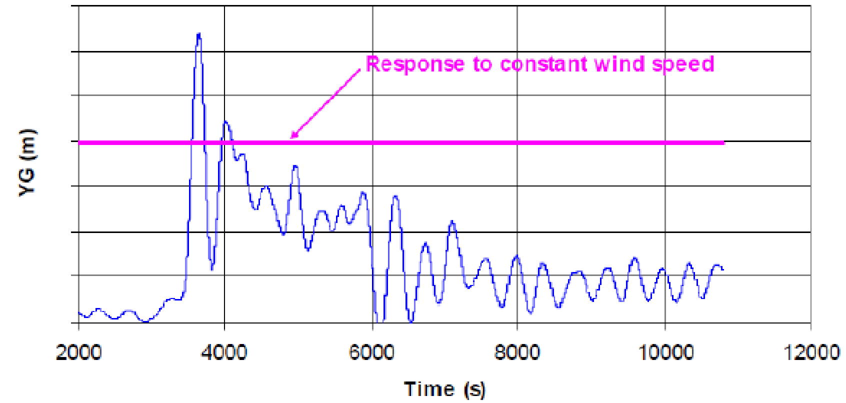
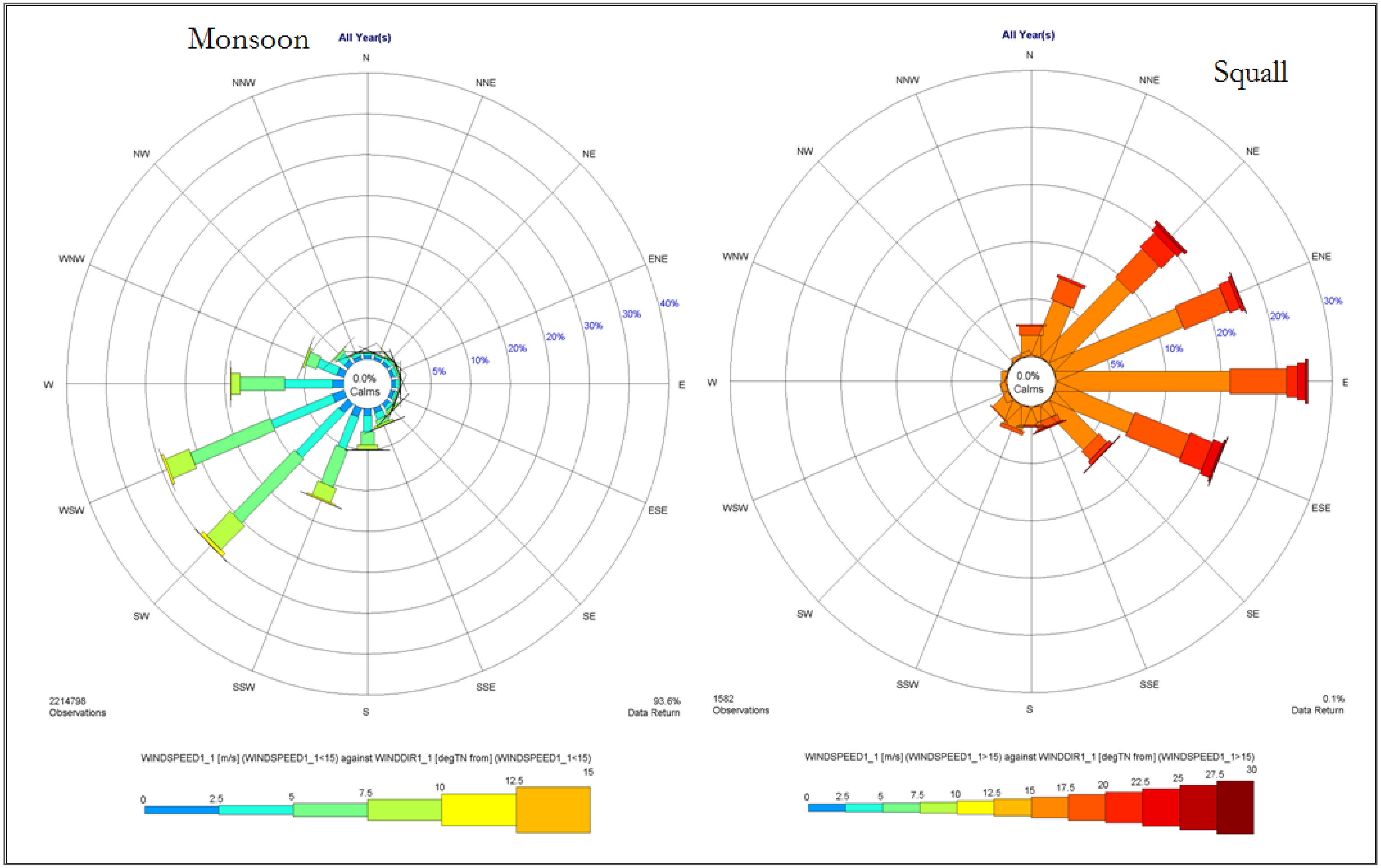


Figure 2-7: Spread-moored FPSO response to Squall versus constant wind (Legerstee, et al. 2006)

- Conservatism of constant wind case is not clear:
  - Over-estimation of responses?
  - Under-estimation of responses?

Directional Metocean Extremes and Failure Modes: Wind



Bonga fpso

Metocean engineering

Real-time Data

+

Long-term Field Data

Long-term Field Data

Operational MetOcean

- operational support
- operational planning
- ocean / weather forecasting
- workability statistics
- risk assessment

MetOcean Design & Analyses

- design criteria: platforms, riser, pipelines, floating structures
- tow / transportation criteria
- site-specific conditions
- oil spill modeling
- fatigue analysis

- *beneficial to operations and engineering improvement*
- *reduce downtime and risks*
- *significant impact on safety, efficiency, and cost*

Metocean requirements for each development phase

PHASE | **METOCEAN CRITERIA**

Rig Selection and Riser Design

- Overview of key metocean processes and hazards for the location.
- Extreme wind, wave and current (1, 10, 100-year return).
- Monthly, seasonal and all-year operational wind, wave and current statistics.
- Current profile characterisation.

Operational Planning

- Overview of key metocean processes and hazards for the location.
- Monthly, seasonal and all-year operational wind, wave and current statistics.
- Monthly persistence statistics for wind, wave and current.
- Principal current direction.

Offshore Drilling and Operations

- Overview of key metocean processes and hazards for the location.
- Monthly, seasonal and all-year operational wind, wave and current statistics.
- Monthly persistence statistics for wind, wave and current.
- Monthly, seasonal and all-year operational wind, wave and current joint occurrence statistics (wind speed and direction, wave height and direction, wave height and period, current speed and direction).
- Monthly, seasonal and all-year maximum current profile.
- Monthly, seasonal and all-year sea water temperature statistics.
- Description of wave spectra.

Production – Fixed structures and jack-ups

- Extremes (typically for 1, 5, 10, 50, 100 and 10,000-year return)
  - Directional wind speeds.
  - Directional Hs and associated parameters (Tp, Tz, Hc, Hmax, THmax).
  - Directional current speeds and current profile.
  - Surge (positive and negative).
  - Maximum and minimum total water level (tide + surge + wave crest).
- Tidal water levels (HAT, LAT, MSL etc).
- Wave scatter diagrams (joint occurrence of Hs and Tp) by direction.
- Individual wave number of occurrences (H and T) for deterministic fatigue analysis.
- Characterisation of directional wave spectra.
- Air and sea temperature.
- Ice, iceberg and snow, if any.

Production – Floating structures

- Extremes (typically for 1, 10 and 100-year return)
  - Directional wind speeds.
  - Directional Hs and associated parameters (Tp, Tz, Hc, Hmax, THmax).
  - Directional current speeds and current profile.
  - Maximum and minimum total water level (tide + surge + wave crest).
- Tidal water levels (HAT, LAT, MSL etc).
- Wave scatter diagrams (joint occurrence of Hs and Tp) by direction.
- Individual wave number of occurrences (H and T) for deterministic fatigue analysis.
- Characterisation of directional wave spectra.
- Contour plots giving combinations of significant wave height and peak periods for a 100-year return period.
- Wind/wave/current angular separation data.
- Air and sea temperature.
- Ice, iceberg and snow, if any.

Metocean requirements: Jack-ups

Production
– Fixed structures and jack-ups

- Extremes (typically for 1, 5, 10, 50, 100 and 10,000-year return)
  - Directional wind speeds.
  - Directional Hs and associated parameters (Tp, Tz, Hc, Hmax, THmax).
  - Directional current speeds and current profile.
  - Surge (positive and negative).
  - Maximum and minimum total water level (tide + surge + wave crest).
- Tidal water levels (HAT, LAT, MSL etc).
- Wave scatter diagrams (joint occurrence of Hs and Tp) by direction.
- Individual wave number of occurrences (H and T) for deterministic fatigue analysis.
- Characterisation of directional wave spectra.
- Air and sea temperature.

Metocean Data for Offshore Structures Design

Design of Fixed Platform Structure

- Structural Concept – Elevations, Framing, Member
- Minimum Airgap – Above 10,00 year Storm
- Dynamic Sensitivity – Modal Response, Fatigue

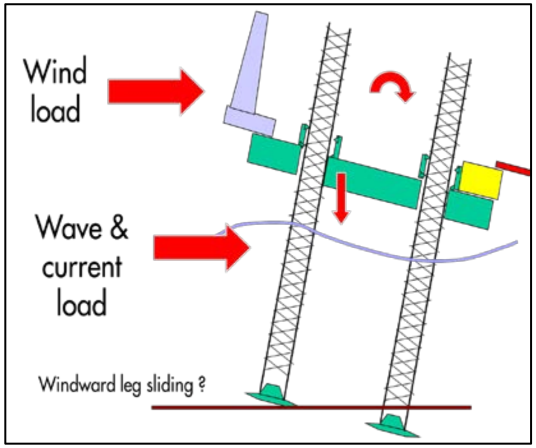
Jack Up Rig Site Specific Assessment

- Feasibility of Jack up Drilling Concept – Location S

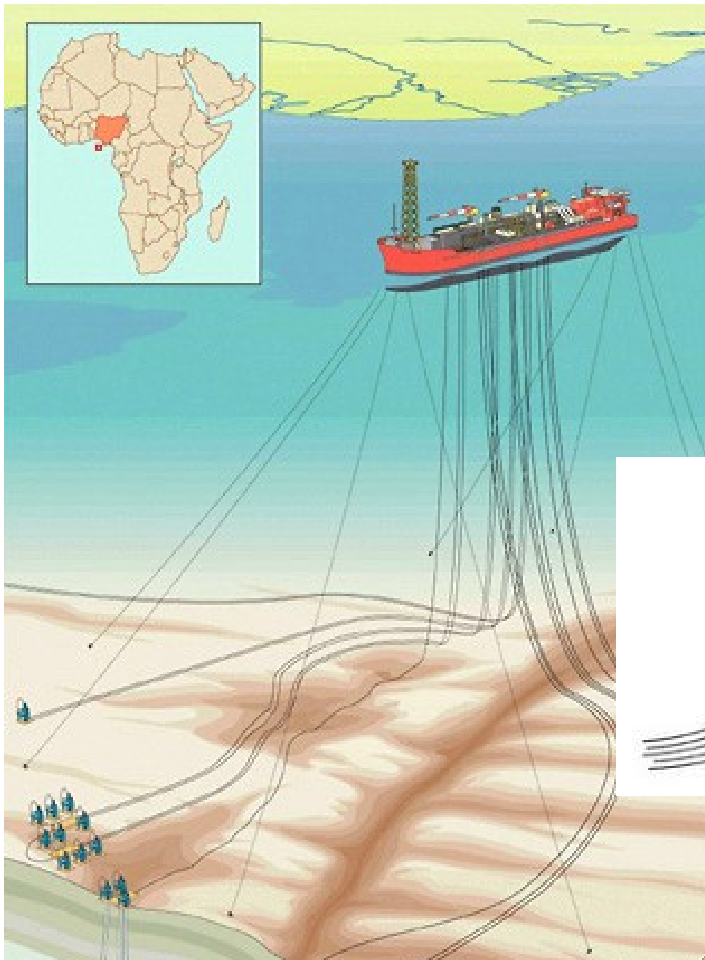
Design for Construction

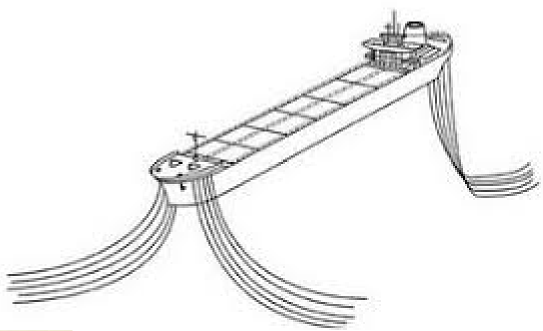
- Weather Window Installation (Lift, Launch etc.)
- Modular or Integrated Platform Concepts
- Pile Connection Point
- Transport Analysis (Topside and Jacket)

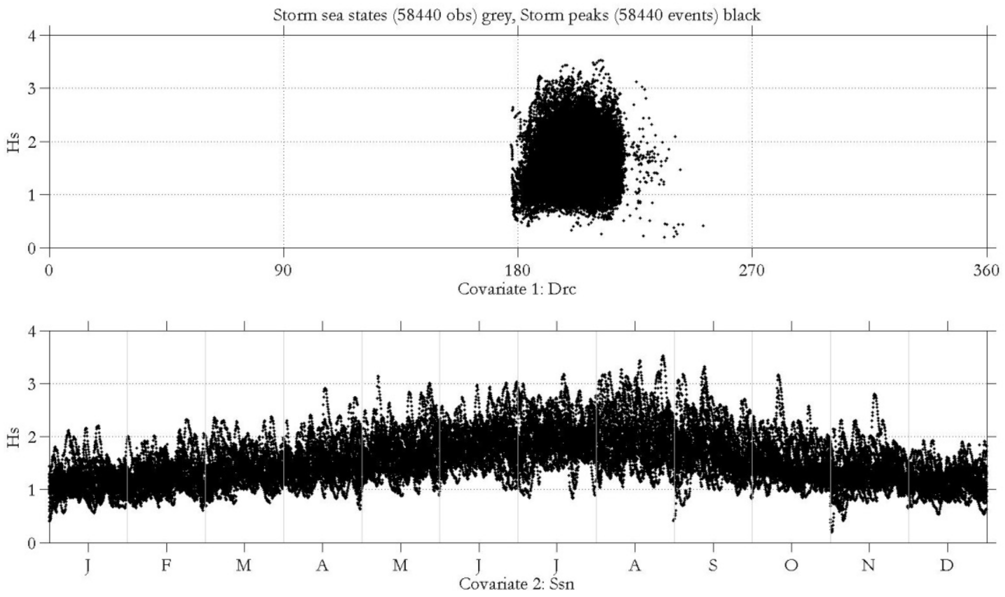
Design for Operations



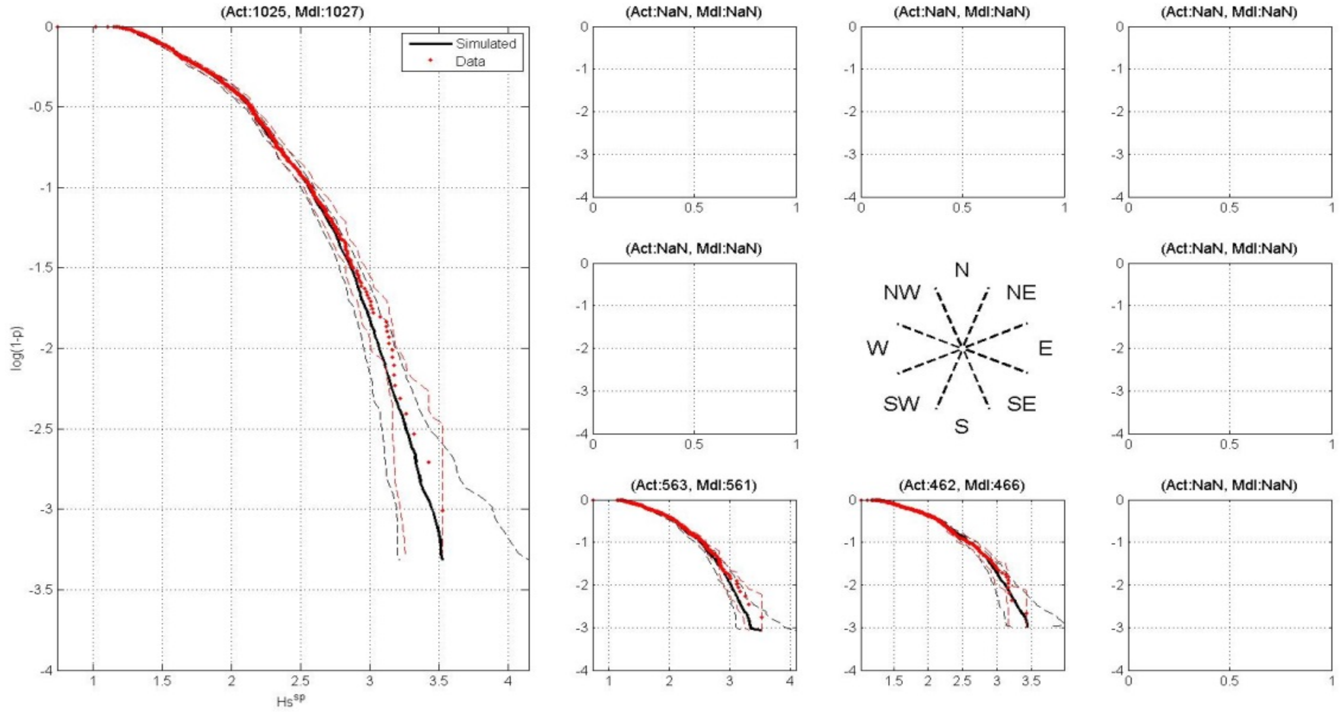
Video Bonga Tandem







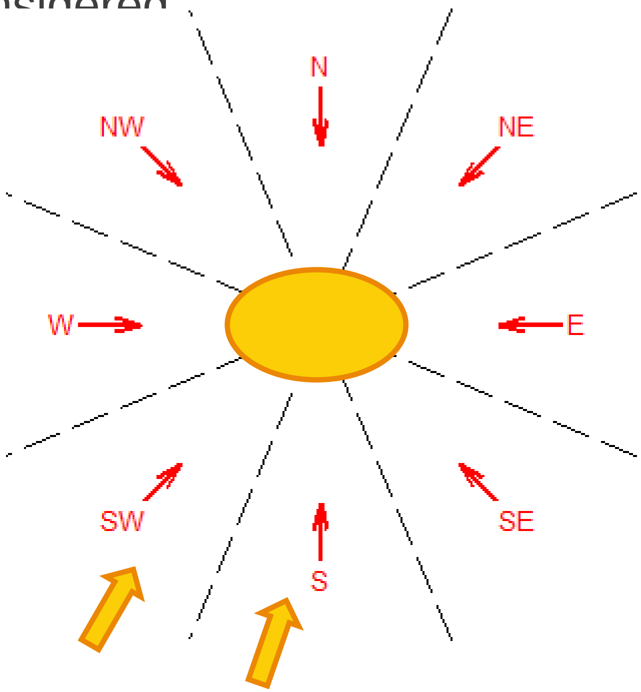
Plot of variate (Hs) against direction (upper panel) and seasons of the year

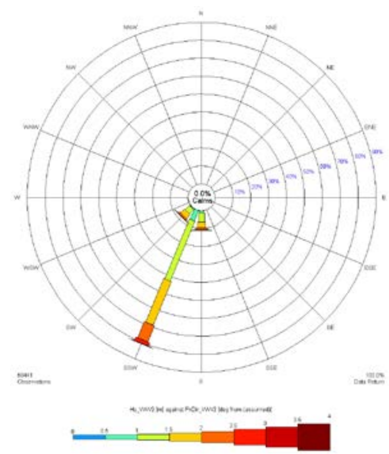


Comparison of observed and fitted data split by direction. Observed data - red lines, model data -black lines. Solid lines represent the median, dashed lines represent the bootstrap 95% confidence range

Directional Metocean Extremes and Failure Modes

Ultimately, we are more interested in the probability of structural failure than in the probability of exceedance of various metocean conditions. In the hypothetical case of a structure, such as that depicted in Figure 5.1, which is infinitely strong in the East-West plane, the waves coming from East and West are effectively irrelevant and only the other 6 directions need be considered.





Directional Extremes

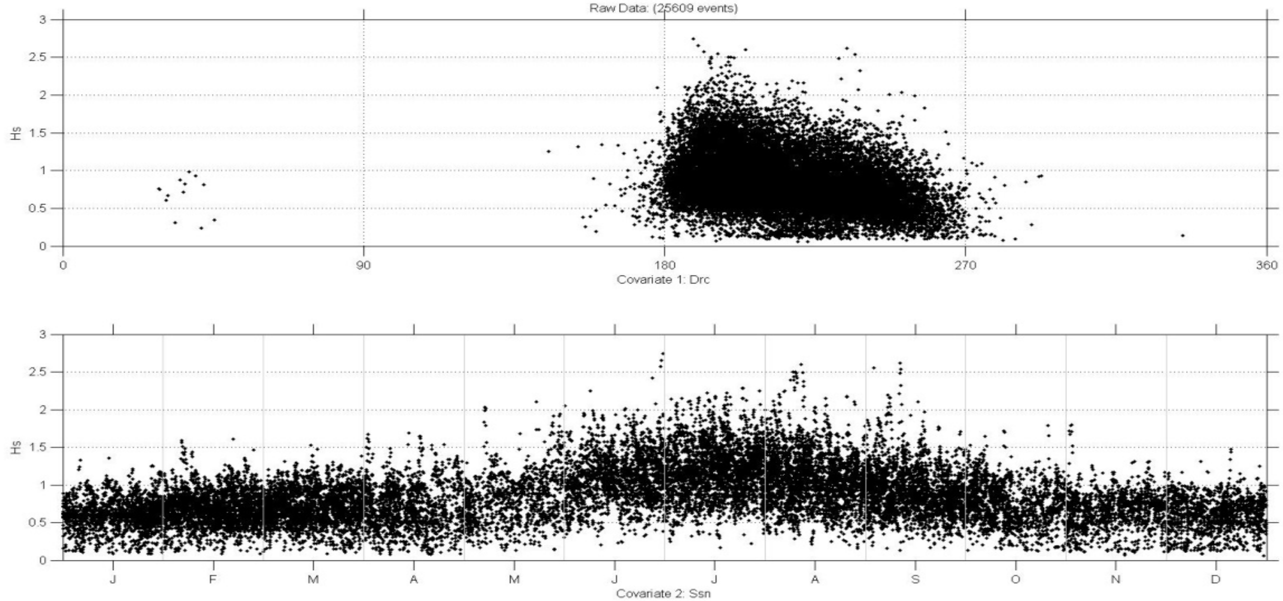
Recommended Wave Height (m)	RETURN PERIOD (YEARS)				
	1	10	100	1000	10000
Hs	2.9	3.3	3.5	3.6	3.7
Hmax	5.9	6.8	7.5	8.1	8.6
Crest	3.3	3.9	4.3	4.6	5.0

Omnidirectional Extreme Wave Heights

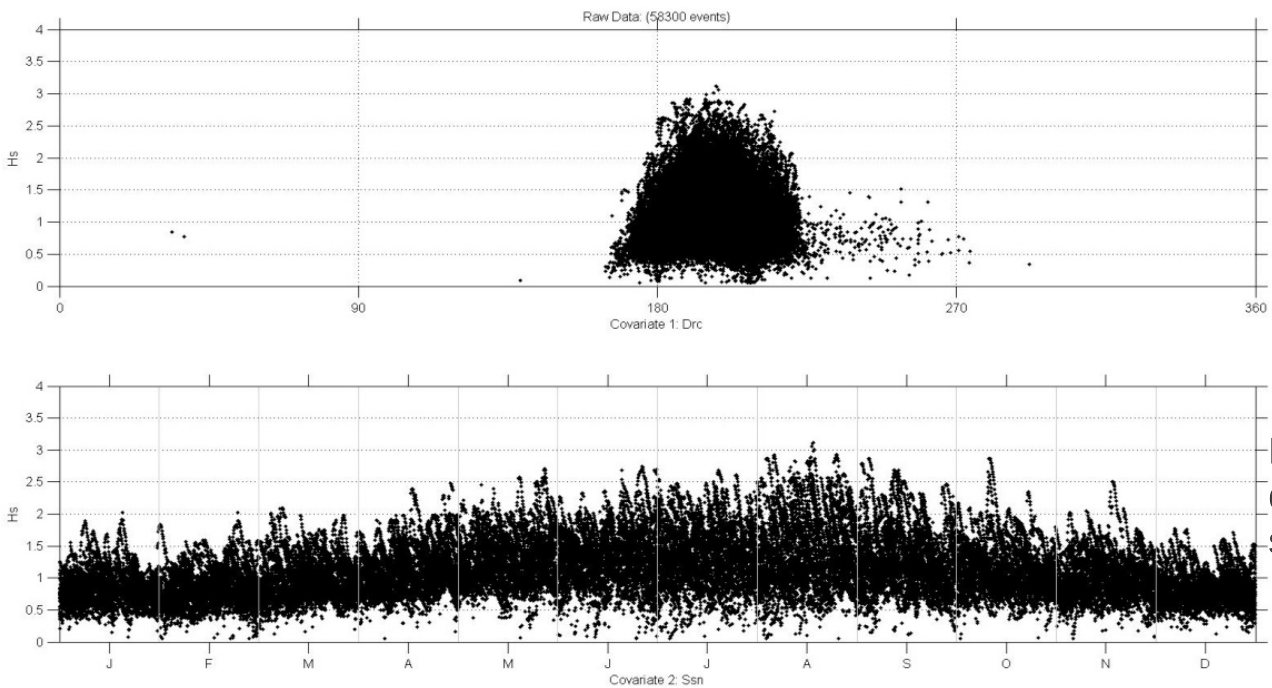
	RETURN PERIOD (YEARS)						
	Independent					100-year Composite	
Hs	**1**	**10**	**100**	**1000**	**10000**	**compositeRV**	**compositeRP**
S	2.9	3.3	3.5	3.6	3.6	3.5	225.5
SW	2.9	3.2	3.4	3.6	3.7	3.5	179.7
Omni	3.0	3.3	3.5	3.6	3.7		
Hmax							
S	5.7	6.6	7.3	8.0	8.5	7.5	186.4
SW	5.7	6.6	7.2	7.8	8.4	7.4	215.8
Omni	5.9	6.8	7.5	8.1	8.6		
Hc							
S	3.2	3.8	4.2	4.6	4.9	4.3	173.3
SW	3.2	3.7	4.2	4.5	4.9	4.3	236.5
Omni	3.3	3.9	4.3	4.7	5.0		
TEWL							
S	3.5	4.1	4.5	4.9	5.3	4.6	205.8
SW	3.5	4.1	4.6	4.9	5.3	4.7	194.5
Omni	3.7	4.2	4.7	5.1	5.4		

Independent & Composite directional Extreme Wave

WindSea & Swell



Plot of variate (Hs) against direction (upper panel) and seasons of the year: **wind-sea**



Plot of variate (Hs) against direction (upper panel) and seasons of the year: **swell**

Directional Extremes

Hs	RETURN PERIOD (YEARS)						
	Independent					100-year Composite	
WindSea	**1**	**10**	**100**	**1000**	**10000**	**compositeRV**	**compositeRP**
S	2.1	2.5	2.8	3.1	3.3	2.9	133.6
SW	1.9	2.3	2.7	3.0	3.4	2.9	397.4
W	1.2	1.6	2.1	2.5	2.8		
NW	0.0	0.0	1.0	1.4	1.7		
Omni	2.2	2.5	2.9	3.2	3.4		
Swell							
S	2.6	3.0	3.2	3.3	3.4	3.2	113.6
SW	2.4	2.8	3.1	3.2	3.3	3.2	835.5
W	0.0	1.3	1.8	2.2	2.4		
NW	0.0	0.0	0.0	0.5	1.6		
Omni	2.6	3.0	3.2	3.4	3.4		


Q&A

Independent and Joint Design Criteria

Part III

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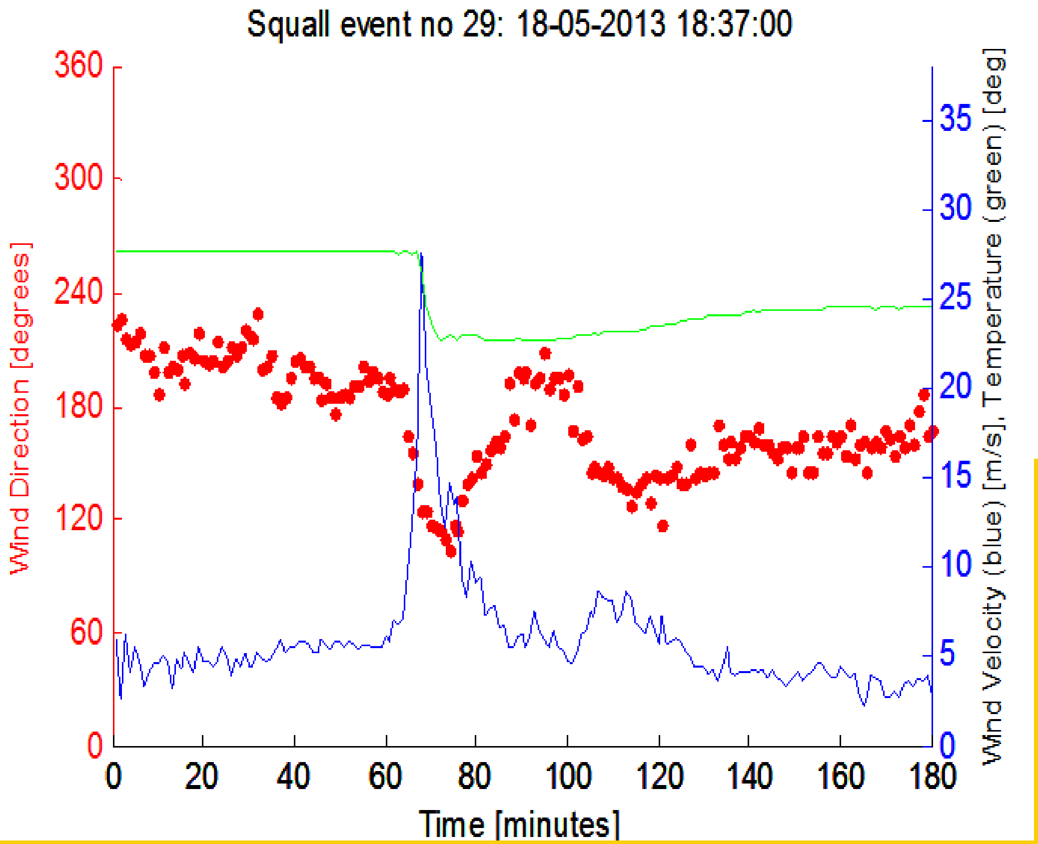
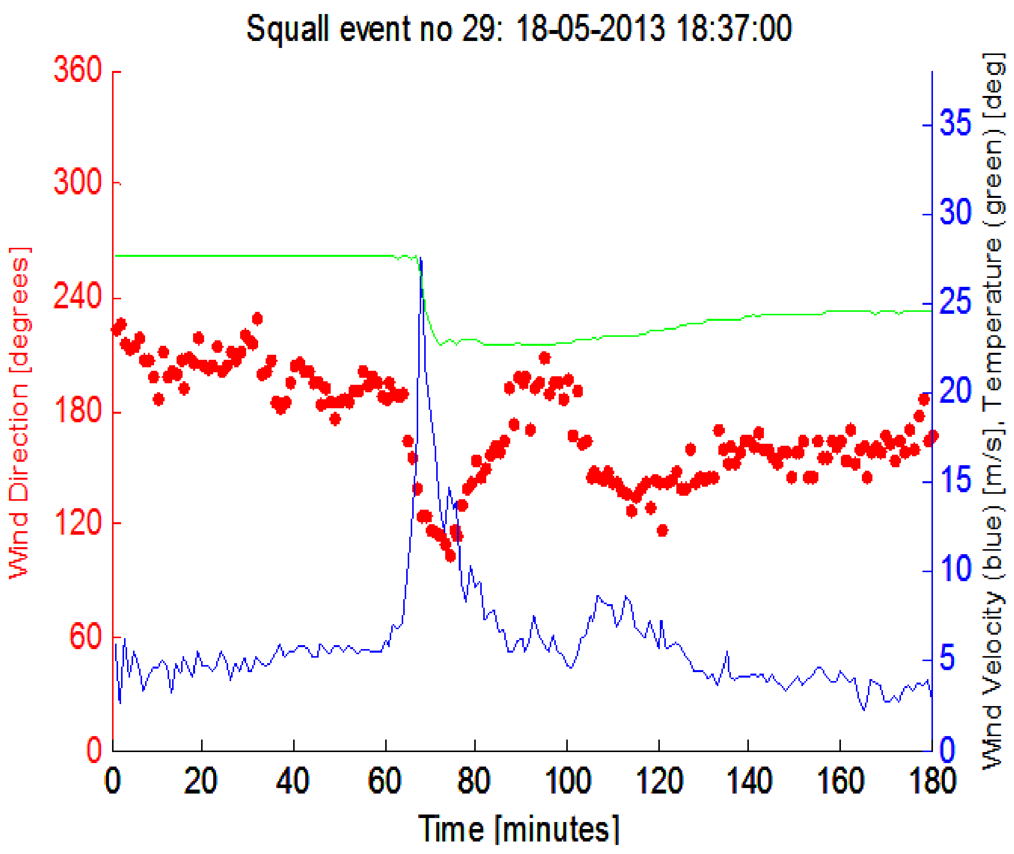


Independent and Joint Design Criteria

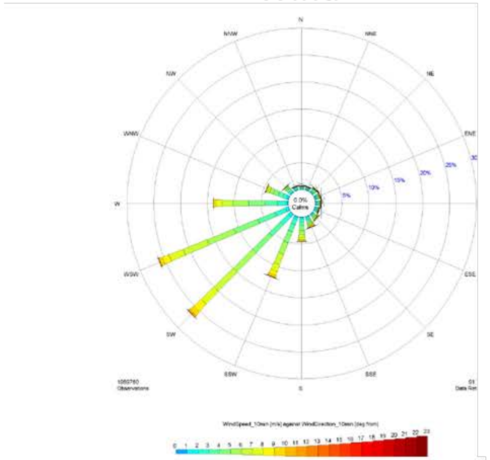
Joint Design Conditions

Correlations between wind, wave and current

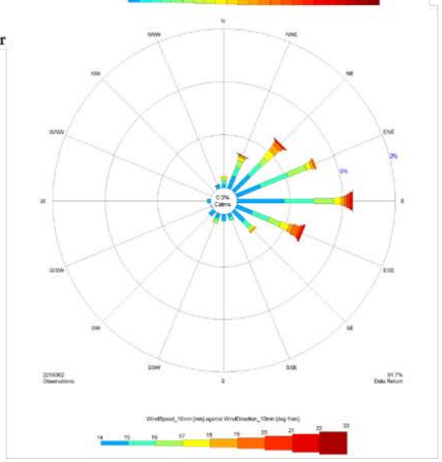


Independent Design Criteria: Offshore West Africa

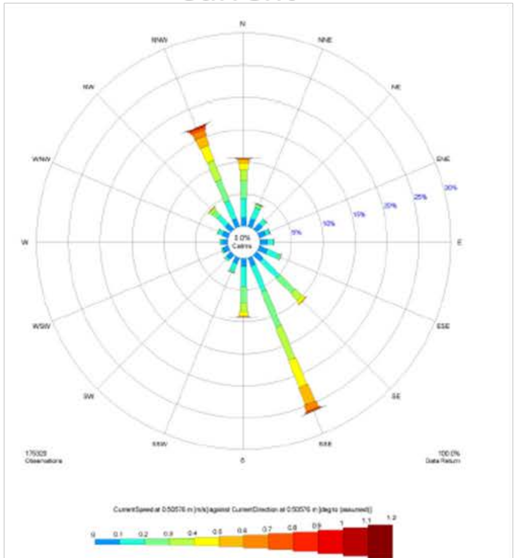
Wind



Figur

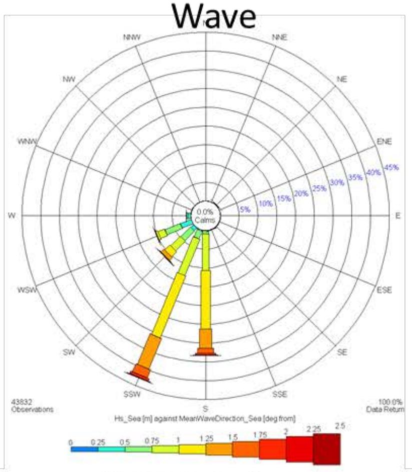


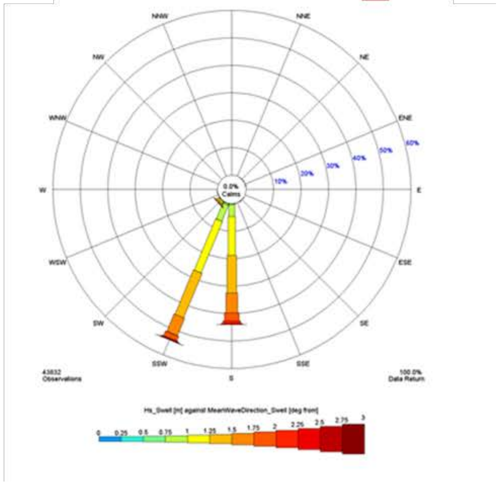
Current



Roseplot at 0.5 m below MSL

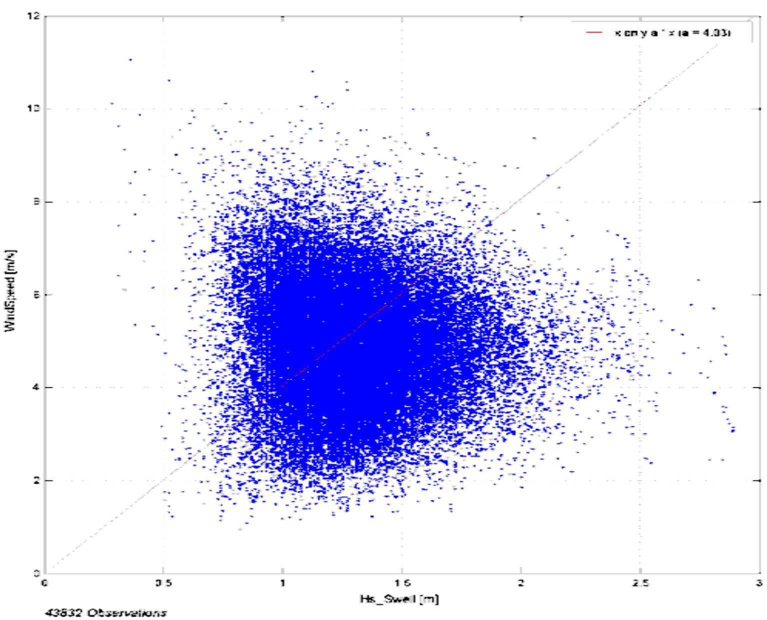
Wave

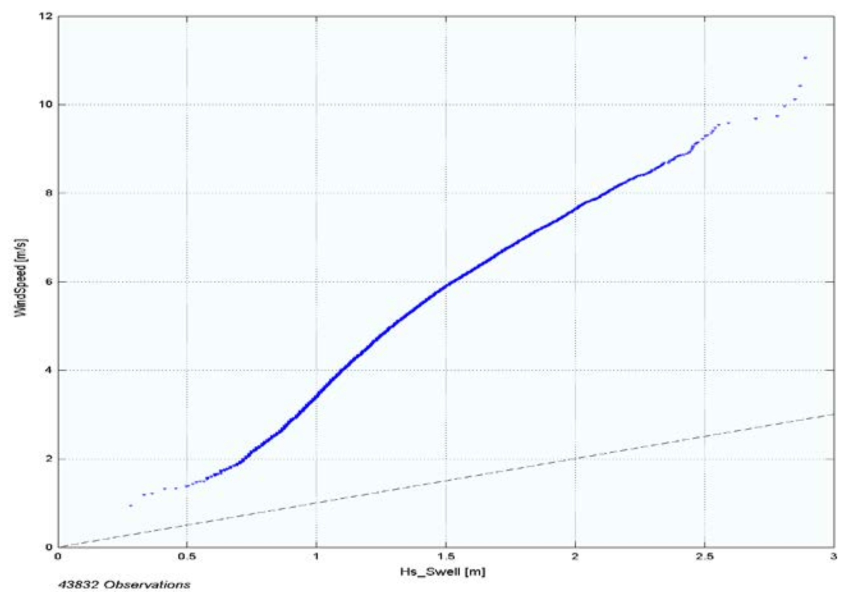




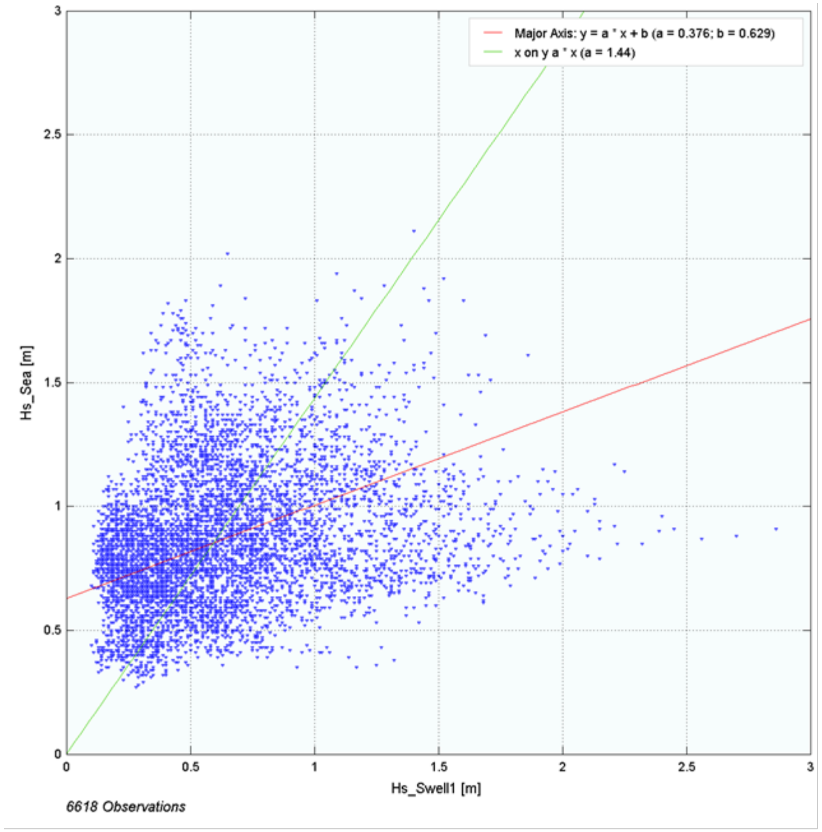
Correlations between wind, wave and current – Offshore West Africa

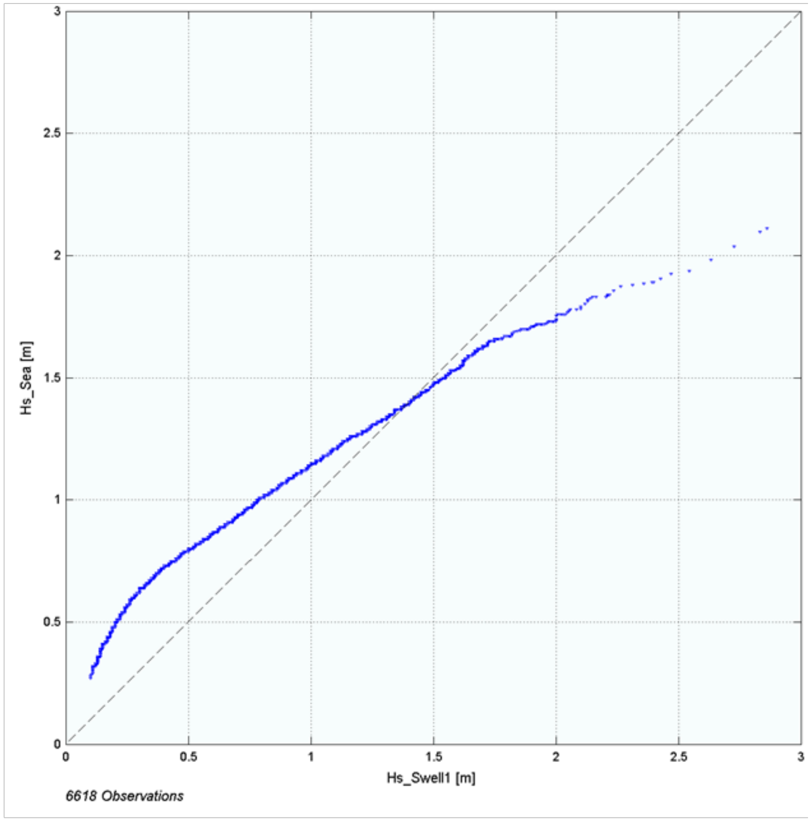
Swell at the site is created by storms far away in the southern ocean. Most of the current appears to be related to the large scale equatorial circulation. It is therefore very likely that the swell height and current speed are statistically uncorrelated with the local wind and waves. The duration of squalls is too short for them to have much effect on waves or currents. A design based on combining the independently derived extreme values of all of these parameters will thus be very conservative.





Independent Design Criteria: Sea & Swell





$$H_{sea} = 0.629 + 0.376 H_{swell}$$

Independent Design Criteria: Current, Wind & Swell

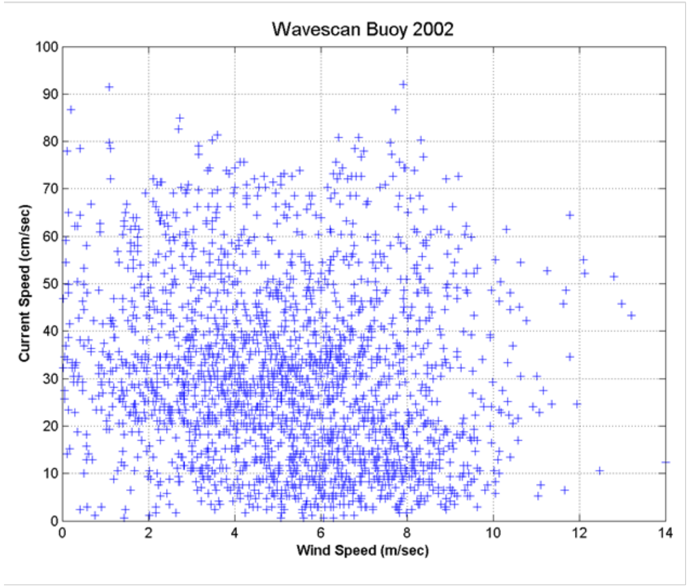


Figure 1: Hourly average current speed at a depth of 2.5 m against hourly average wind speed at 3 m elevation measured by the Wavescan buoy. The correlation coefficient is -0.1465.

A regression of current speed against wind speed gives

$$CS = 0.3604 - 0.0108WS$$

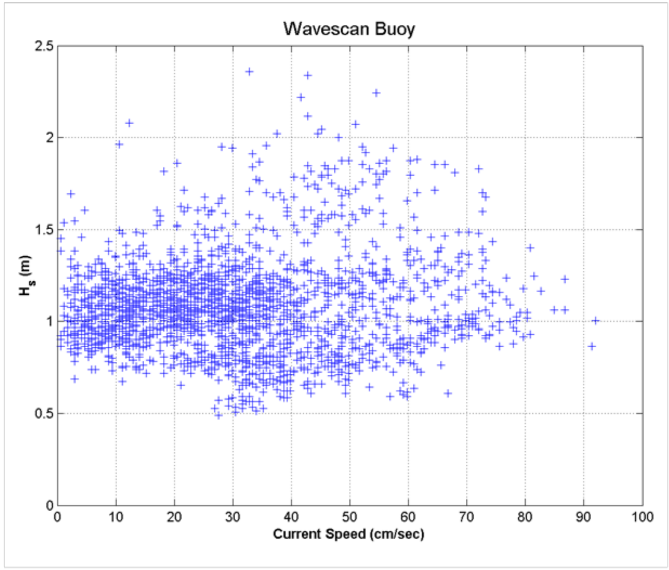


Figure 1: Hourly average current speed at a depth of 2.5 m against significant wave height measured by the Wavescan buoy. The correlation coefficient is 0.0827

A regression of current speed against wave height gives

$$CS = 0.2244 + 0.1094H_{swell}$$

Independent Design Criteria

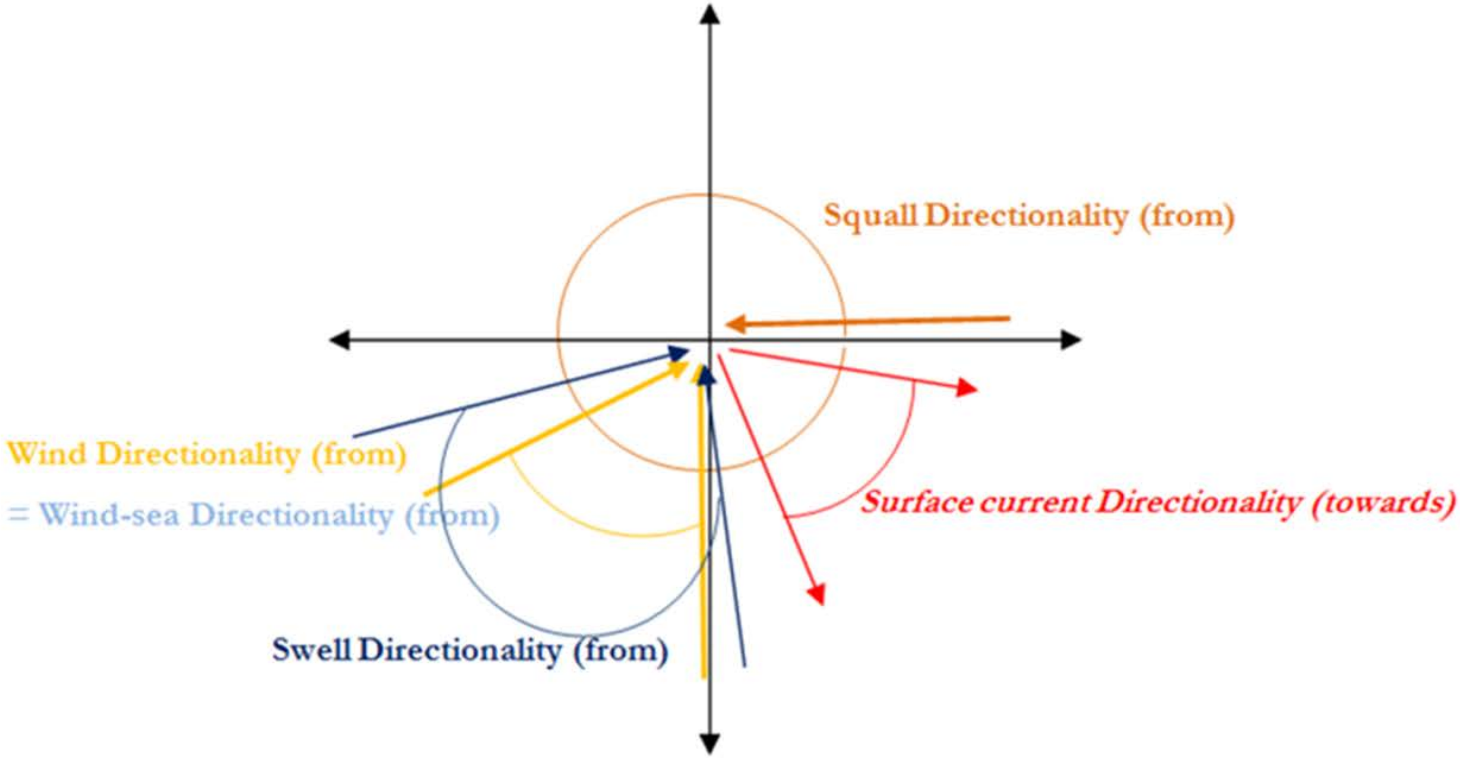


Figure 6.2.3: Graphical representation summarising dominant directions of metocean parameters (Note directional conventions used)

Independent Design Criteria: Sea & Swell

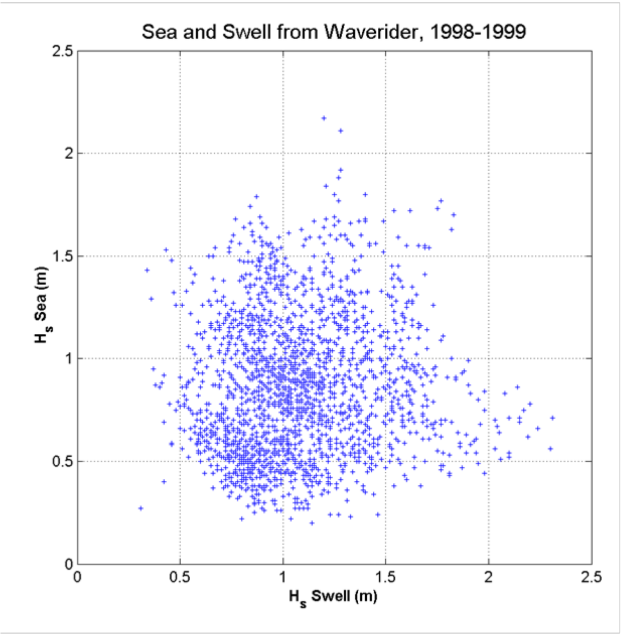


Figure 1: Significant heights of the sea and swell partition of the wave spectrum measured by the Waverider buoy. The correlation coefficient is 0.0688.

A linear regression of swell on sea gives

$$H_{sea} = 0.7835 + 0.0721 H_{swell}$$

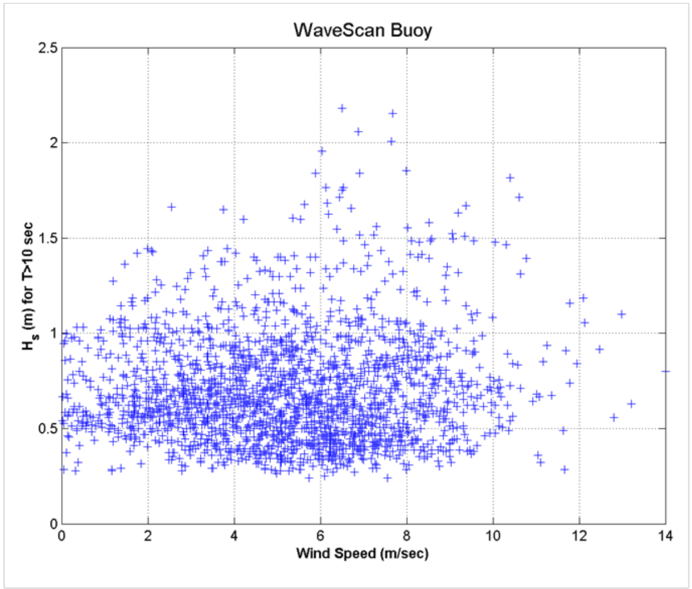


Figure 1: Measured swell (partition of spectrum with periods than 10 seconds) from the Wavescan buoy against wind speed measured on the same buoy at a height of 3 m.

a regression of sea on swell gives

$$H_{swell} = 1.0178 + 0.0655 H_{sea}$$

Independent Design Criteria

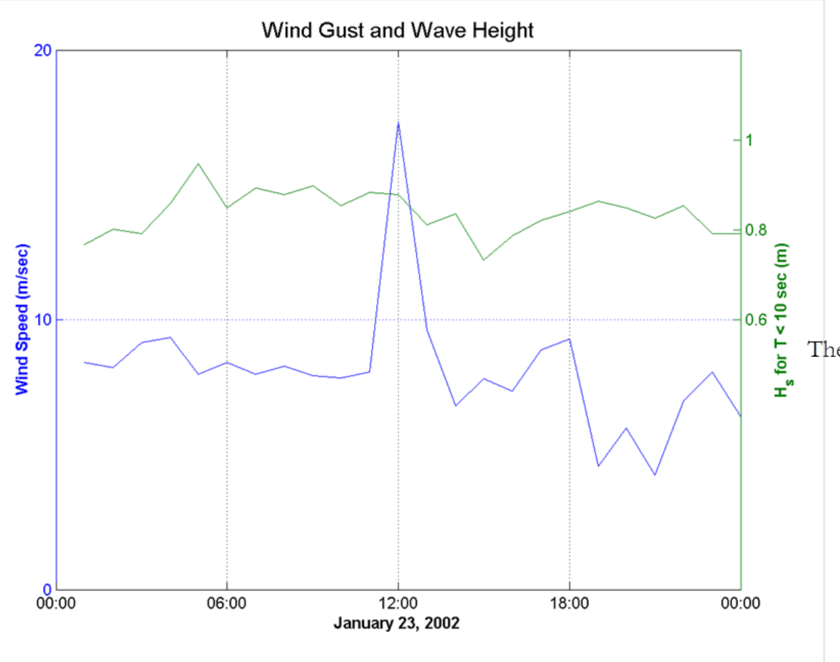


Figure 1: Hourly values of 3 second wind speed and wave height (sea partition) during the squall of January 23, 2002.

The squall apparently has no effect at all on the wave height

Joint Design Criteria

If wind, wave and current conditions are nearly uncorrelated, it would be unduly conservative to design for their extremes to occur simultaneously.

For preliminary design and concept selection, this method is used to develop several design cases in which one feature of the environment is extreme and the other features have the most probable values associated with this extreme. The calculations make use of the regression equations developed previously to find the associated.

If two parameters are statistically independent, then the most probable value of the second parameter associated with the extreme value of the first parameter is its mean value.

Joint Design Criteria

If two parameters are statistically independent, then the most probable value of the second parameter associated with the extreme value of the first parameter is its mean value.

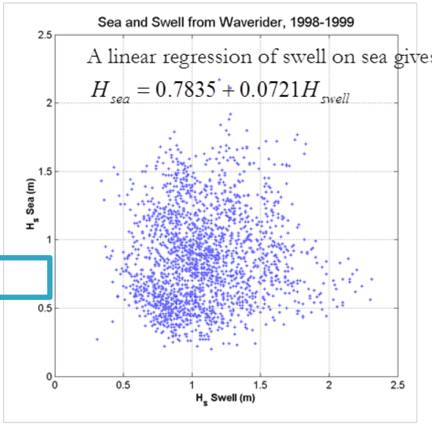
$$H_{sea} = \overline{H}_{sea} + s\left(H_{swell}^{100} - \overline{H}_{swell}\right)$$

Joint Design Criteria

For the swell dominated design case, the extreme values of swell are taken from the independent analysis (previous slides). To compute the most probable locally **generated** seas associated with these extreme values of swell, we use the slope of the regression line in equation 8.1. The associated sea height is then its mean value increased by the slope times the difference between the 100 year wave height and its mean value, or

$$A_{100} = \bar{A} + s(B^{100} - \bar{B})$$

$$H_{sea} = \overline{H}_{sea} + s(H_{swell}^{100} - \overline{H}_{swell}) = 0.86 + 0.0721(3.17 - 1.27) = 1.00$$



A linear regression of swell on sea gives

$$H_{sea} = 0.7835 + 0.0721 H_{swell}$$

Figure 1: Significant heights of the sea and swell partition of the wave spectrum measured by the Waverider buoy. The correlation coefficient is 0.0688.

Extreme swell characteristics derived from the WANE storm

	1 yr	10 yr	100 yr	10,000 yr
Significant wave height (m)	2.20	2.81	3.17	3.64
Period of spectral peak (sec)	14.8	17.9	19.7	22.0
Maximum wave height (m)	4.84	5.99	6.89	8.45
Maximum crest elevation (m)	2.67	3.30	3.80	4.66
Period of maximum wave (sec)	14.8	17.9	19.7	22.0

Independent

Extreme local sea characteristics derived from the Waverider measurements.

	1 yr	10 yr	100 yr	10,000 yr
Significant wave height (m)	2.13	2.35	2.54	2.86
Period of spectral peak (sec)	8.36	8.84	9.26	9.96
Maximum wave height (m)	3.92	4.45	4.94	5.88
Maximum crest elevation (m)	2.37	2.71	3.03	3.63
Period of maximum wave (sec)	7.52	7.96	8.33	8.97

Criteria for extremes dominated by swell

	1 yr	10 yr	100 yr	10,000 yr
Swell				
Significant swell height (m)	2.20	2.81	3.17	3.64
Swell peak period peak (sec)	14.8	17.9	19.7	22.0
Period of maximum swell (sec)	14.8	17.9	19.7	22.0
Swell direction (from)	185	185	185	185
Sea				
Local sea significant height	0.93	0.97	1.00	1.03
Local sea peak period	8.36	8.84	9.26	5.97
Local sea direction (from)	225	225	225	225


Q&A