

FOWPI Metocean Workshop



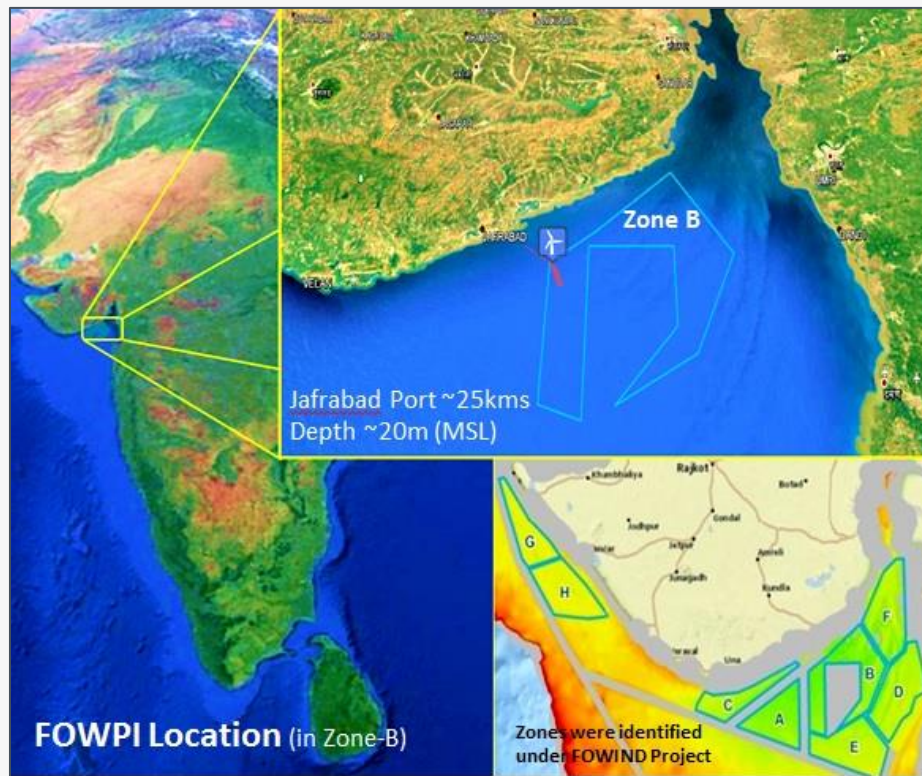
Modelling, Design Parameters and Weather Windows

Jesper Skourup, Chief Specialist, **COWI**



Agenda

1. Metocean Data Requirements
2. Site Description
3. Bathymetry
4. Data (Tidal, Wind, Wave)
5. Modelling Software
6. Model Calibrations
7. Hindcast Simulations
8. Data Analysis
9. Cyclone Conditions
10. Weather Windows
11. Summary
12. Recommendations



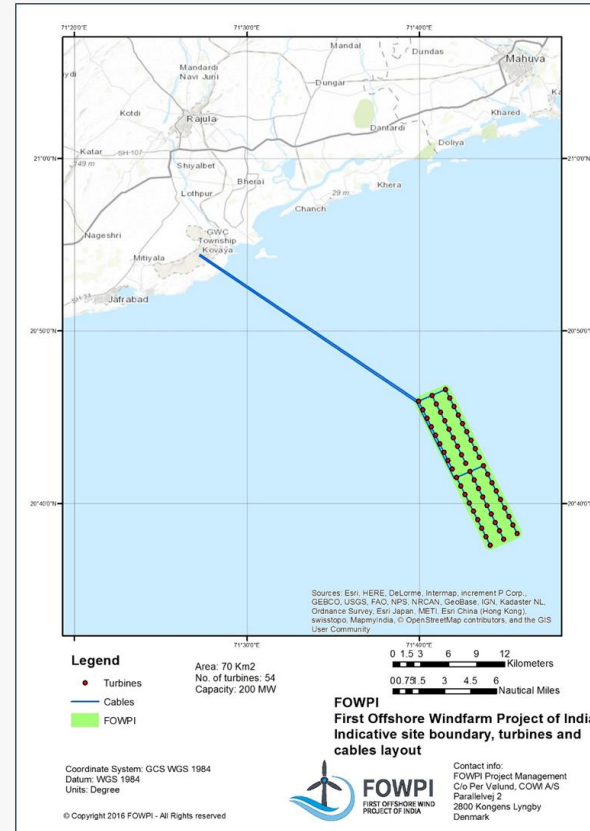
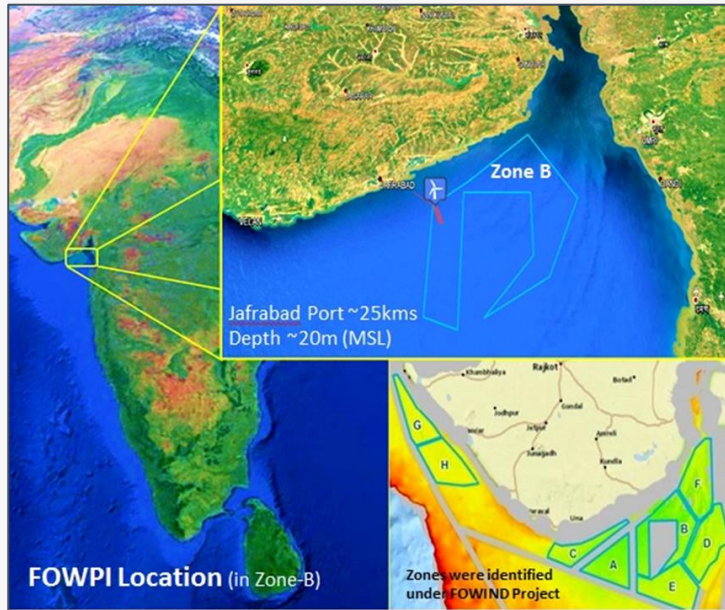
1. Metocean Data Requirements

- COWI Metocean Data Requirements
- Adjust to governing standards
 - Mainly **IEC 61400-3** for present project
- Considered during early phase of project
- Comprehensive and validated metocean data may save lots of time and money during design phase
- Reliable metocean data also needed for planning of transportation and installation of foundations and turbines



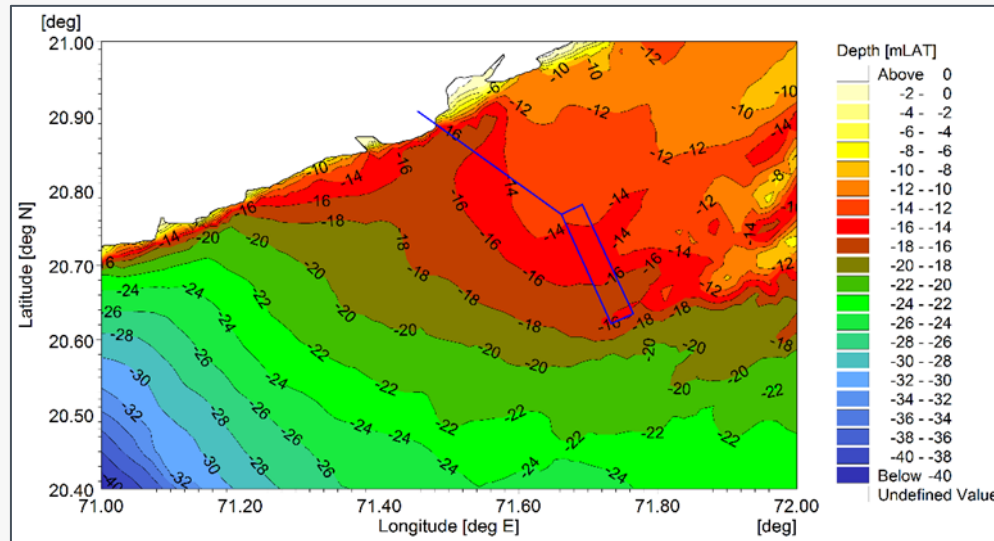
2. Site Description

- Gulf of Khambhat in the Gujarat region



3. Bathymetry

- Based on MIKE C-Map (a digital sea chart including all depths and land boundary data as given in nautical sea charts)
- MIKE C-Map datum is LAT
- Conversion to MSL for simulations
- Combination with measured data would be preferable
- Local bathymetry → → → → → → → →

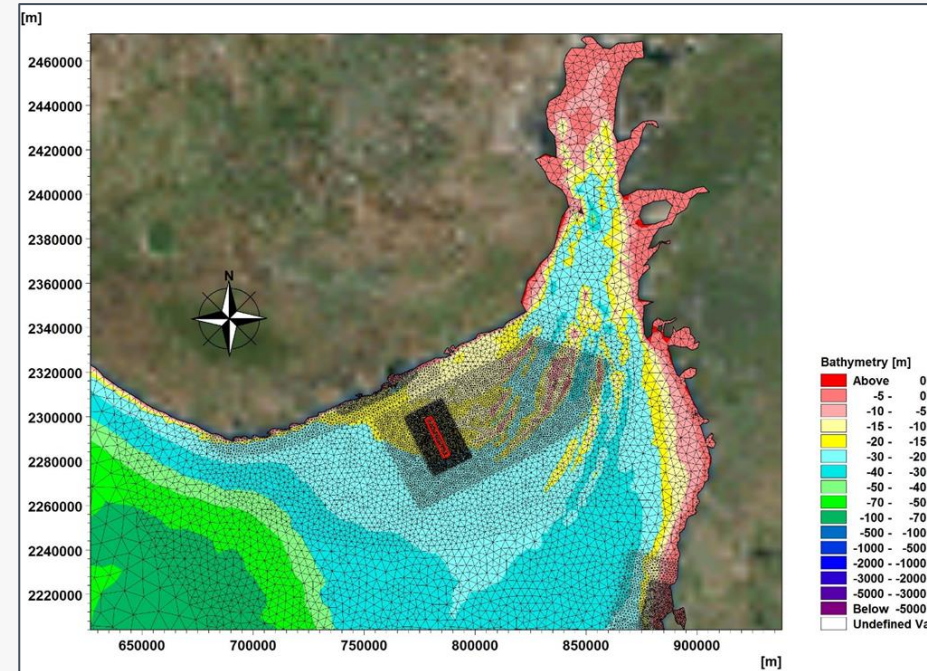


4. Data (Tidal, Wind, Wave)

- Needed for set-up, calibration and running computational models (hydrodynamic and wave)
- Tidal data as boundary conditions from global tidal model by DHI
- Tidal data for validation of computational HD model based on local tidal constituents
- Wind velocity and barometric pressure in model area from ECMWF ERA-Interim reanalysis hindcast model
- Wave data as boundary conditions from NOAA WAVEWATCH III wave hindcast model
- Buoy measurements of wave data from Indian National Centre for Ocean Information Services (INCOIS) for model calibration

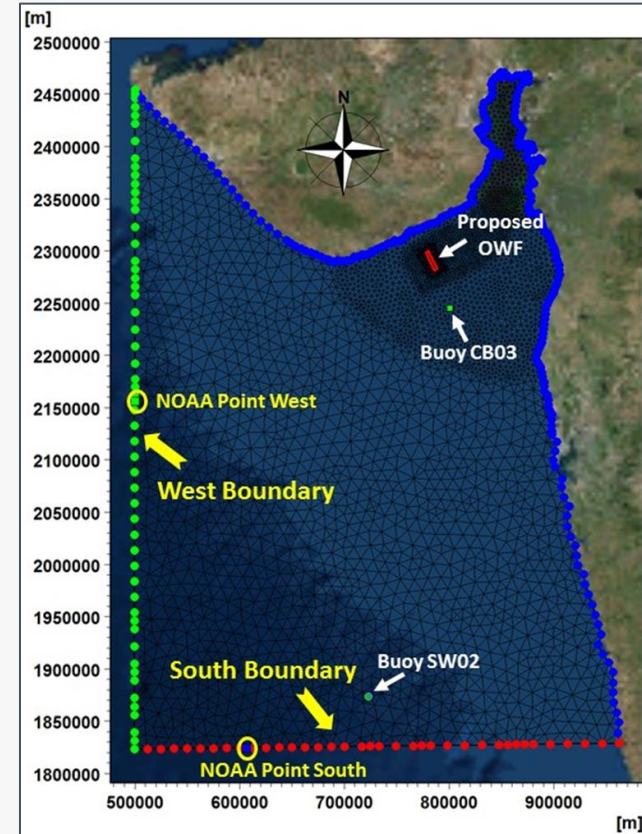
5. Modelling Software (1)

- Hydrodynamic modelling by **MIKE 21 Flow Model HD FM**
- Simulates unsteady flow taking into account bathymetry, sources and external forcing
- Application areas:
 - Hydrographical conditions in non-stratified waters
 - Coastal flooding
 - Storm surge
 - inland flooding and overland flow
 - Forecast and warning systems



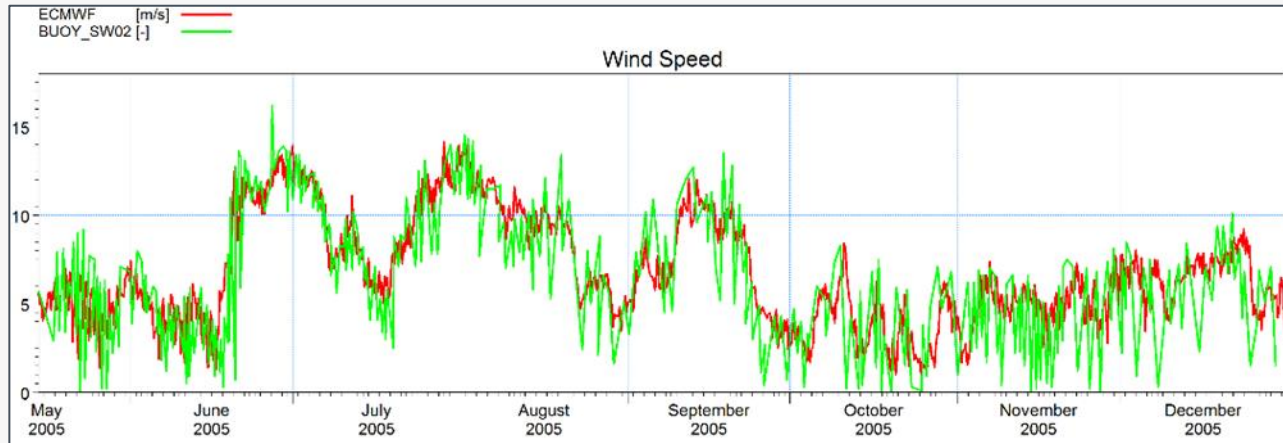
5. Modelling Software (2)

- Spectral Wave modelling by **MIKE 21 SW**
- State-of-the-art 3rd generation spectral wind-wave model
- Fully spectral formulation based on a wave action conservation equation
- Includes following physical phenomena:
 - Wave growth by action of wind
 - Nonlinear wave-wave interaction
 - Dissipation due to white capping
 - Dissipation due to bottom friction
 - Dissipation due to depth induced wave breaking
 - Refraction and shoaling due to depth variations
 - Wave-current interaction
 - Time varying water depth



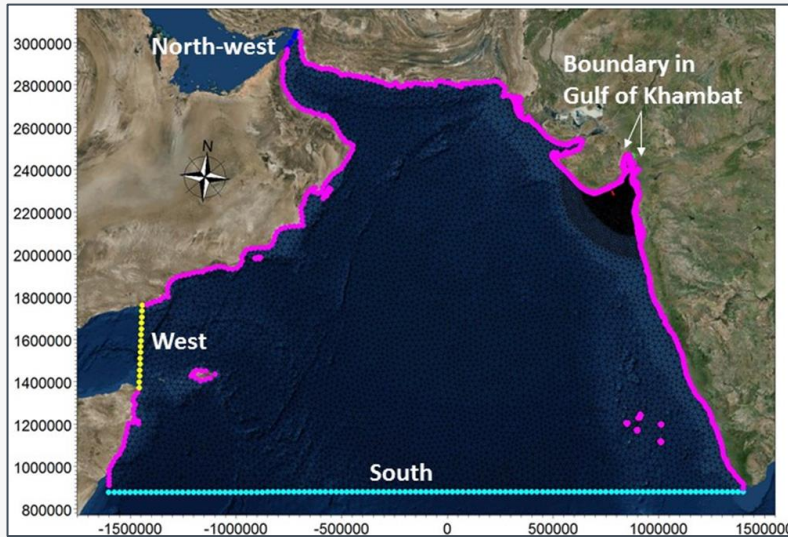
6a. Model Calibrations: Wind

- Comparison of ECMWF wind speed and digitized measurements from INCOIS SW02 buoy

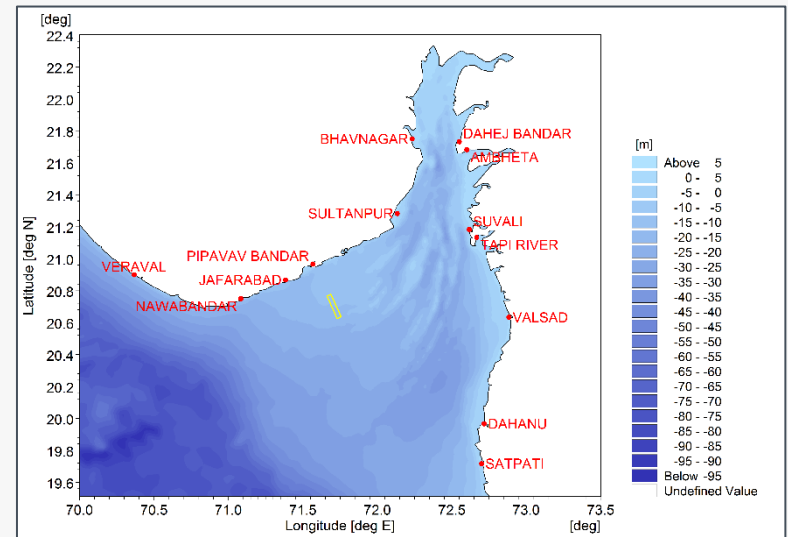


6b. Model Calibrations: Water Level (1)

Model Area

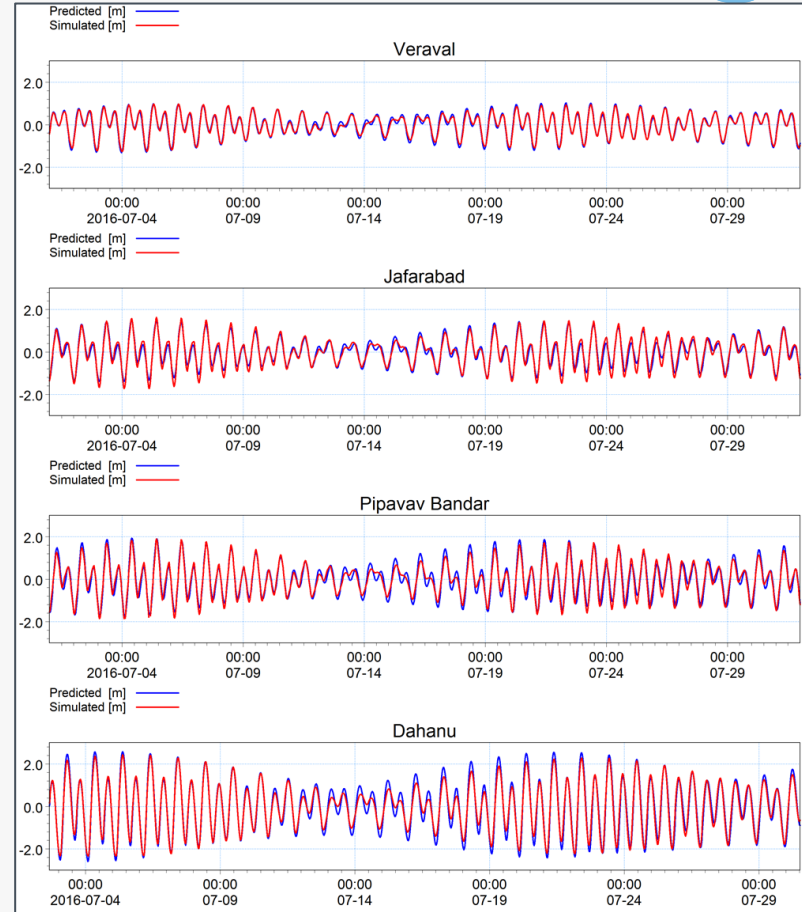
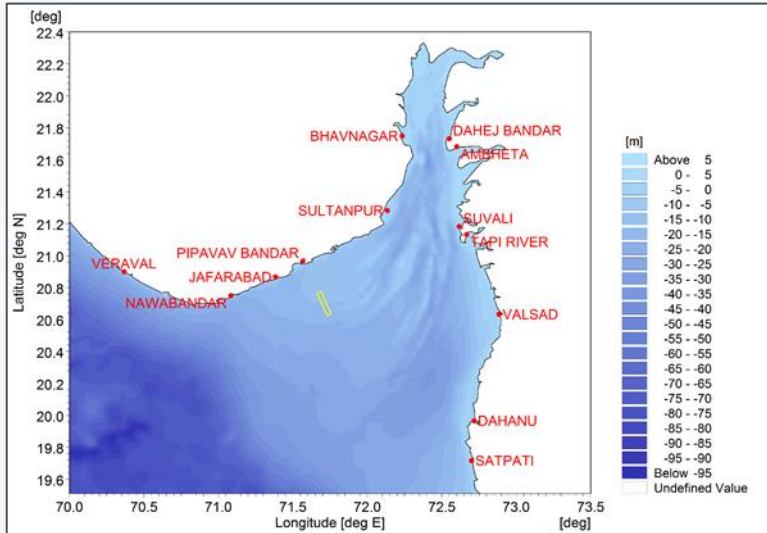


Extraction Points

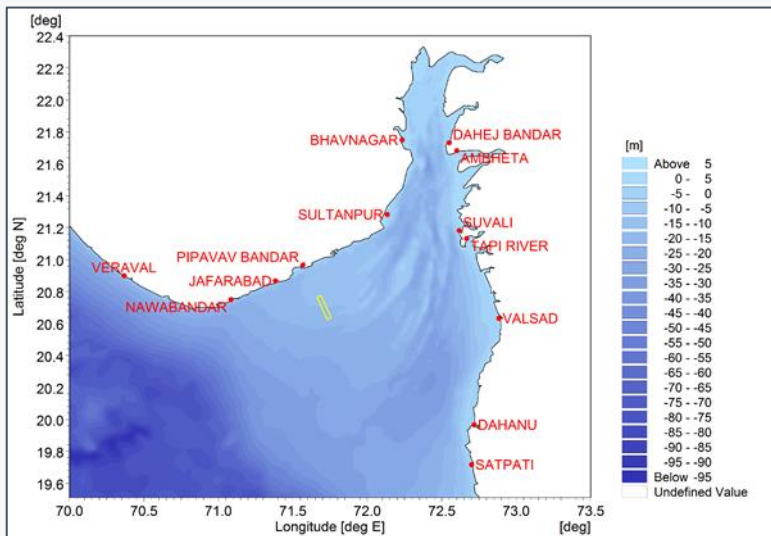


6b. Model Calibrations: Water Level (2)

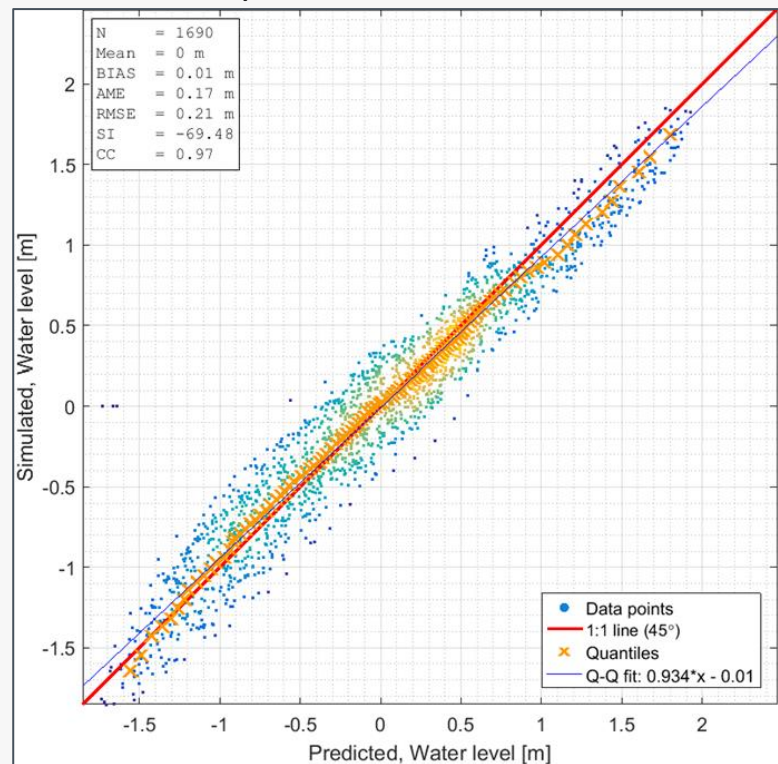
Time Series Comparison



6b. Model Calibrations: Water Level (3)



Pipavav Bandar: Q-Q Plot

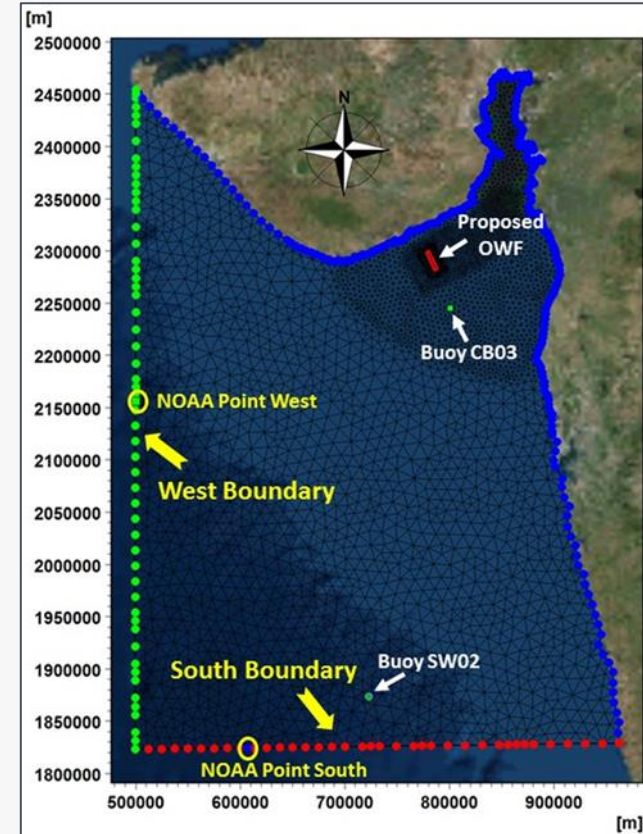


6c. Model Calibrations: Waves (1)

- **INCOIS Buoy data**

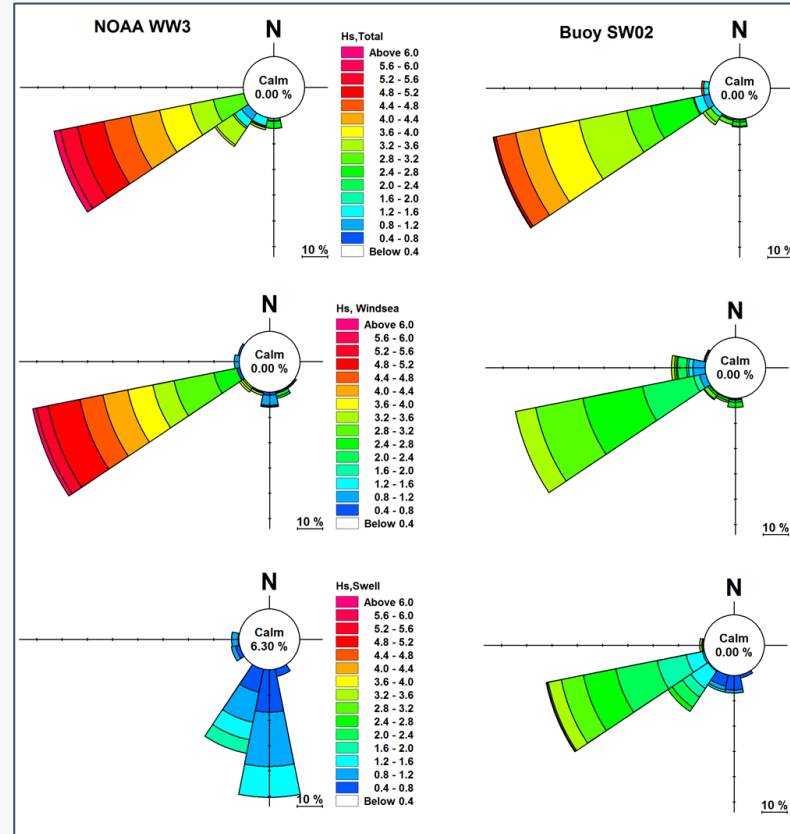
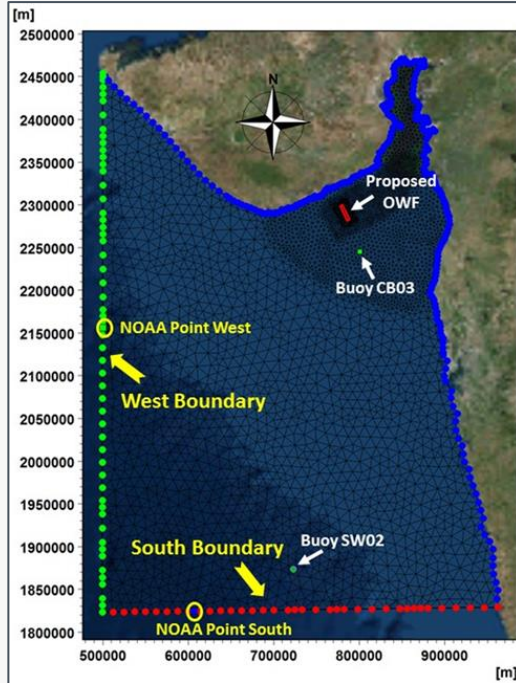
Buoy	Latitude/Longitude	Period
CB03	20.27802°N, 71.87767°E	19-05-2012 to 18-06-2012
SW02	16.95142°N, 71.11353°E	01-06-2008 to 01-07-2008

- Significant wave height, mean wave period, mean wave direction of total, windsea and swell waves
- Height of highest wave (total wave), $H_{\max}$ and wave period of the highest wave
- High frequency wave direction
- Peak wave period, zero crossing wave period, wave direction at spectral peak or Peak wave direction of the total wave.
- Directional spread at spectral peak
- Unidirectivity index (spectral bimodality index)



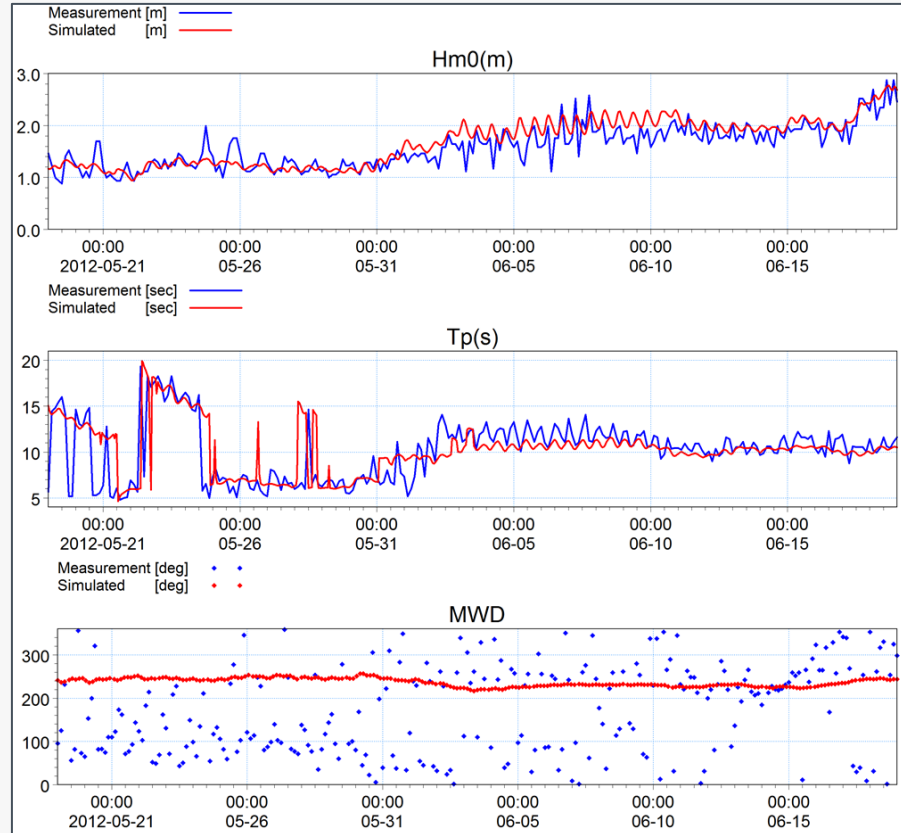
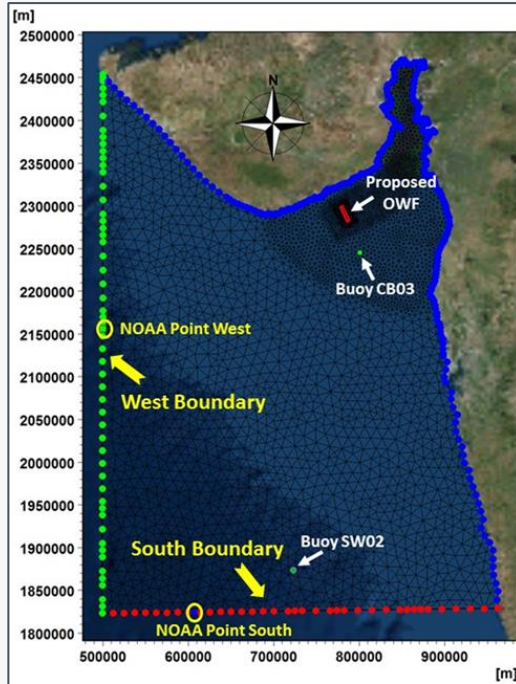
6c. Model Calibrations: Waves (2)

SW02: Rose Data



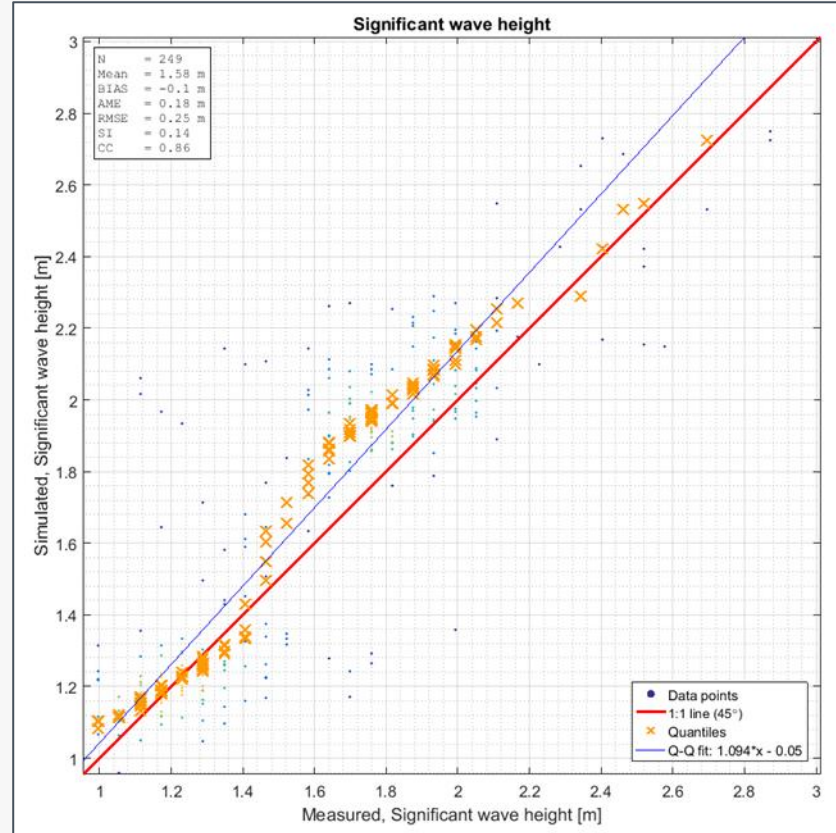
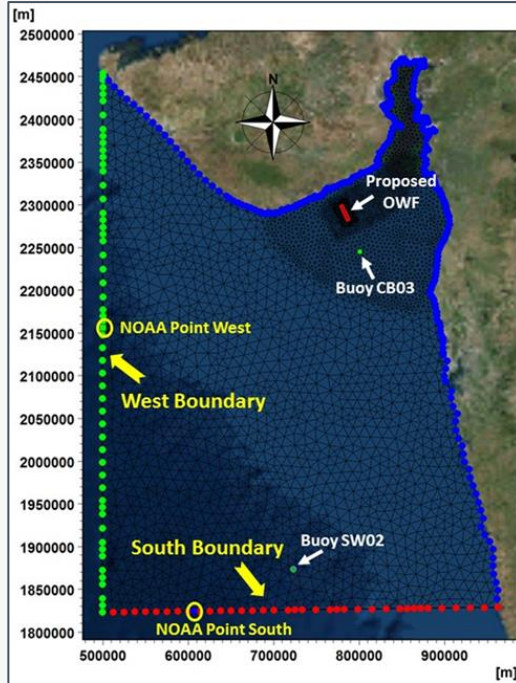
6c. Model Calibrations: Waves (3)

CB03: Time Series



6c. Model Calibrations: Waves (4)

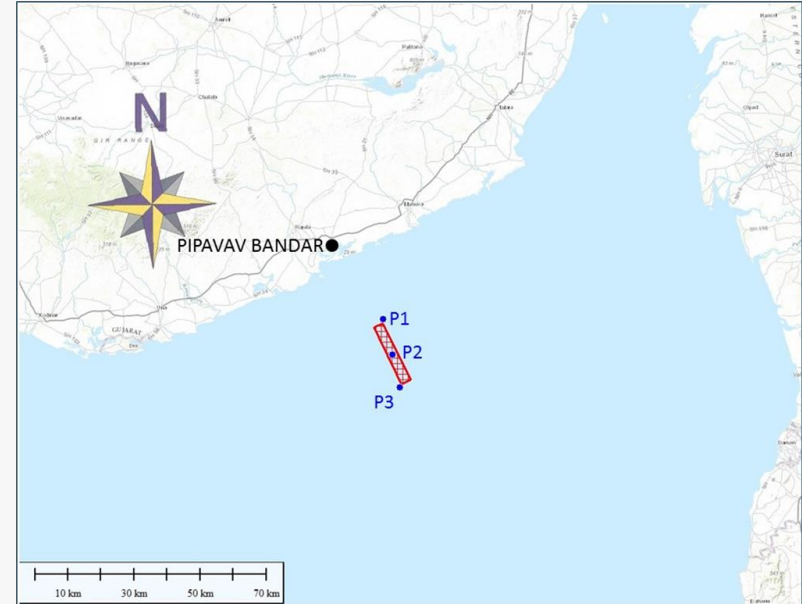
CB03: Q-Q Plots



7. Hindcast Simulations (1)

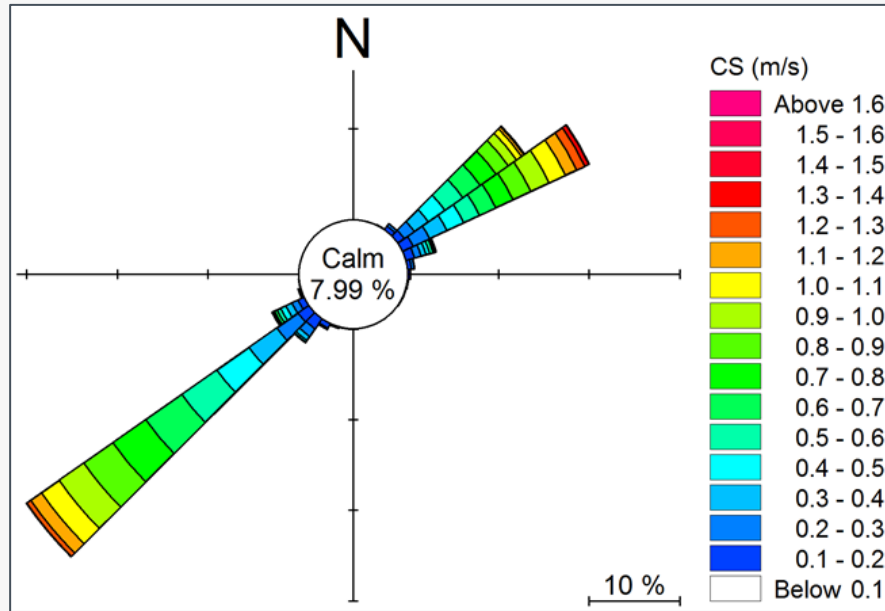
- Hindcast during 5 year period (2010-2014)
- **MIKE 21 Flow Model HD FM** for hydrodynamic conditions
- **MIKE 21 SW** for spectral wave conditions
- Hourly Data extraction at 3 points P1, P2 & P3
- Water level, Current & Wave data

Extraction points	UTM42, Easting [m]	UTM42, Northing [m]
P1	780428	2301062
P2	783217	2290278
P3	785314	2280430

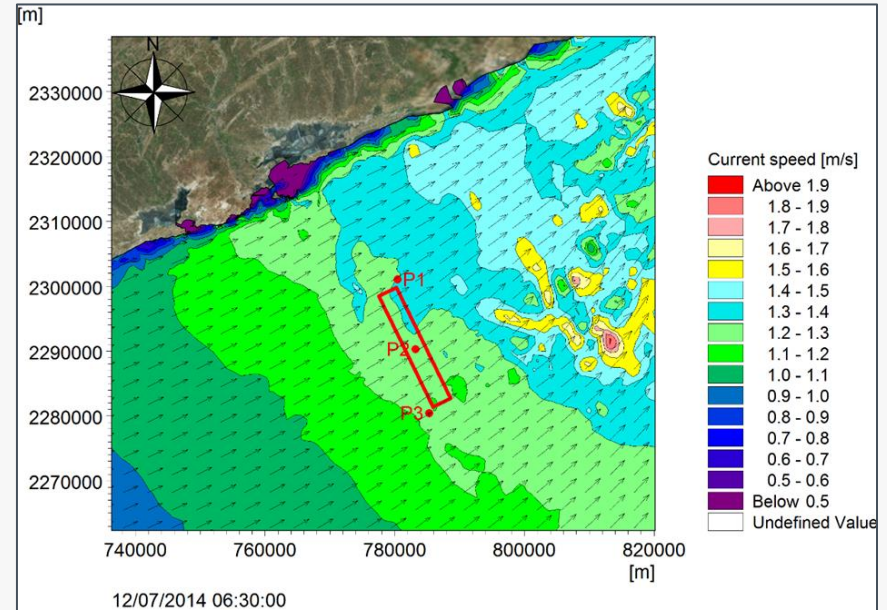


7. Hindcast Simulations (2): Current Data

P2: Current rose

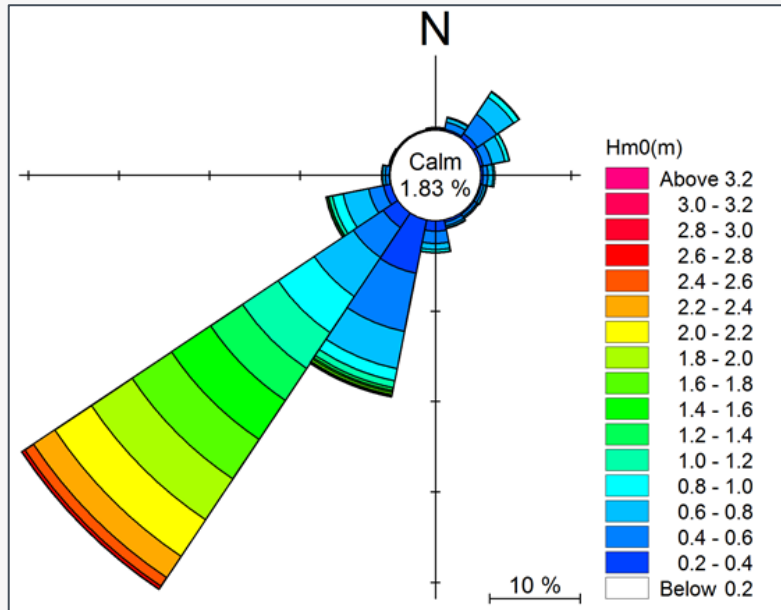


Flow characteristics during flood flow

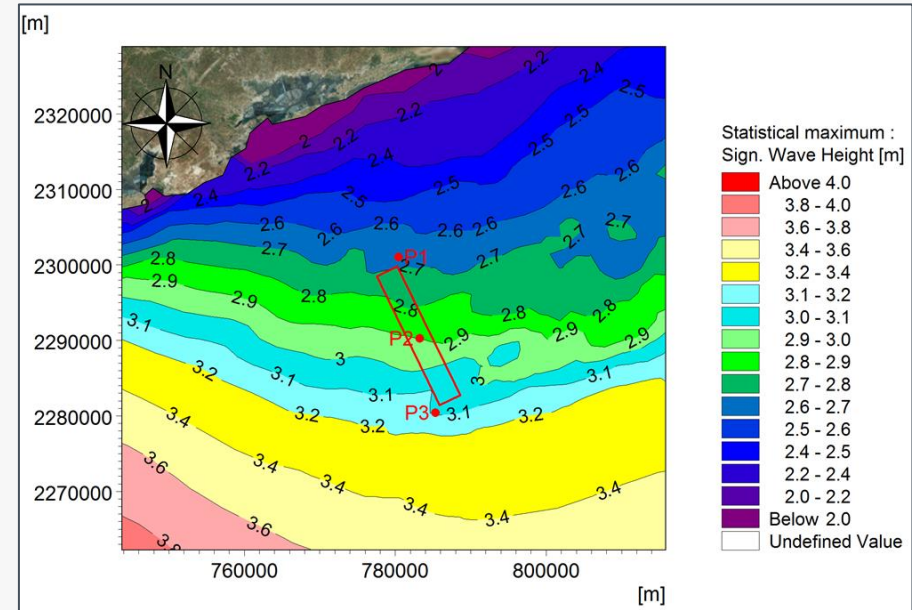


7. Hindcast Simulations (3): Wave Data

P2: Wave rose

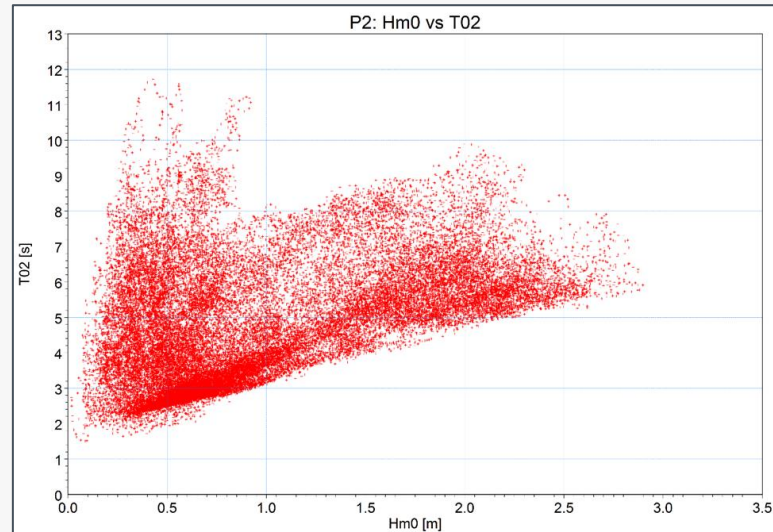


Maximum significant wave height



8. Data Analysis (1): General

- Data analysis in compliance with IEC 61400-3:2009 (supplemented by DNV-RP-C205 & DNV-OS-J101)
- Directional data per 12 directions centred on 0, 30, ..., 330 degN
- Monthly and directional statistics
- Rose plots and frequency tables
- Scatter plots and tables
- Wind-wave misalignment tables
- Extreme value analysis
- Cyclone hindcast study
- Weather windows



8. Data Analysis (2): Wind

- ECMWF ERA-Interim data from (71.6874°E, 20.7761°N) used for analysis
- Conversion from 3-hour average to 10-minute average by following relation

$$U(T, Z) = U_{10} \left(1 + 0.137 \ln \left(\frac{Z}{10} \right) - 0.047 \ln \left(\frac{T}{10} \right) \right)$$

ref: DNV-RP-C205, section 2.3.2.11

- Z is reference height (in mMSL) and T is average period (in minutes)
- *It is emphasized that this Metocean report does not constitute a full wind study, which would be required for wind turbine design or wind resource assessment. The analysis of the wind data carried out in this study is solely intended for foundation design.*

8. Data Analysis (3): Waves

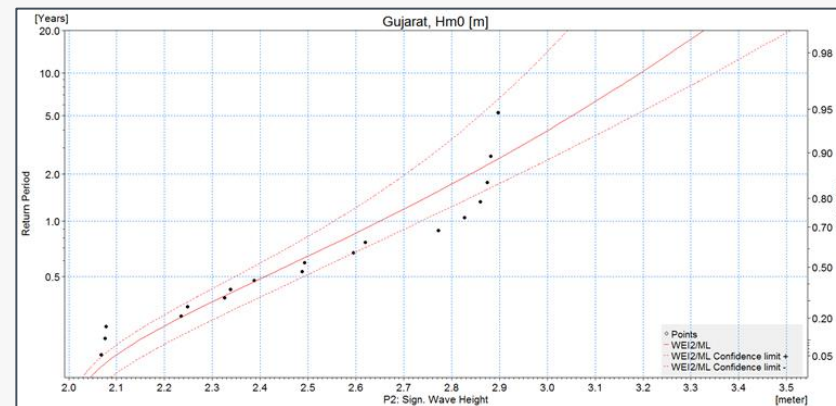
- **Normal Sea States (NSS):** The significant wave height, peak spectral period and direction for each normal sea state shall be selected, together with the associated mean wind speed, based on the long term joint probability distribution of metocean parameters appropriate to the anticipated site
- **Severe Sea States (SSS):** The severe stochastic sea state model shall be considered in combination with normal wind conditions for calculation of the ultimate loading of an offshore wind turbine during power production. The severe sea state model associates a severe sea state with each wind speed in the range corresponding to power production
- **Extreme Sea States (ESS):** The extreme stochastic sea state model shall be considered for both the extreme significant wave height, H_{s50} , with a recurrence period of 50 years and the extreme significant wave height, H_{s1} , with a recurrence period of 1 year

8. Data Analysis (4): Waves

Extreme Value Analysis (EVA) of H_{m0}

- Peaks-over-threshold (POT) method
- 3-parameter Weibull fit
- Location parameter fixed at threshold
- 1, 5 and 10 years return period
- Confidence bands by Monte Carlo simulations
- H_{max} , T_{Hmax} and η_{max} by DNV-RP-C205 and stream function theory

Weibull fit



Parameter	Return Period [Years]		
	1	5	10
H_{m0} [m]	2.7	3.1	3.2
H_{max} [m]	5.0	5.8	6.0
T_{Hmax} [s]	6.6	7.1	7.2
η_{max} [m]	3.0	3.6	3.8

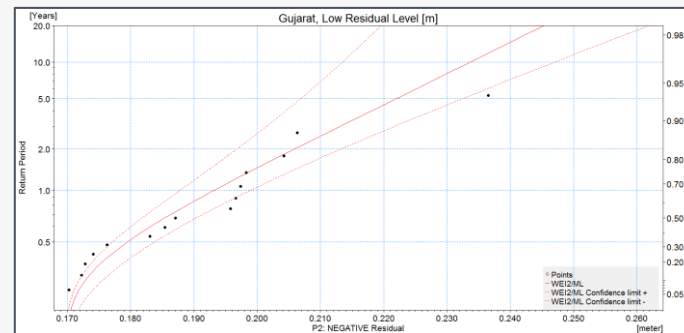
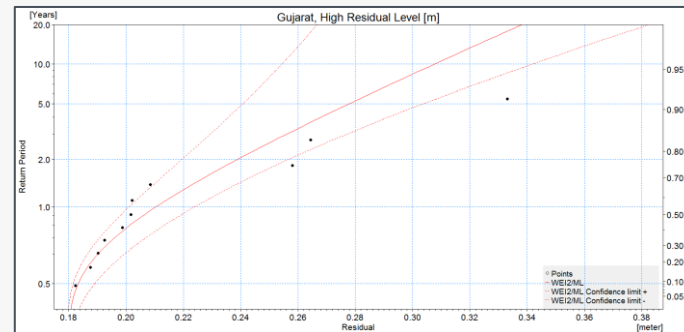
8. Data Analysis (5): Water Level

Extreme Value Analysis (EVA) of WL

- Tidal analysis: Total WL → Tidal & Residual WL
- 3-parameter Weibull fit
- Location parameter fixed at threshold
- 1, 5 and 10 years return period
- Confidence bands by Monte Carlo simulations
- High & Low residual WL

High Residual Level [m]	Return Period [Years]		
	1	5	10
Central estimate	0.21	0.28	0.31
Standard deviation	0.02	0.03	0.04
Recommended value	0.23	0.31	0.35

Weibull fits



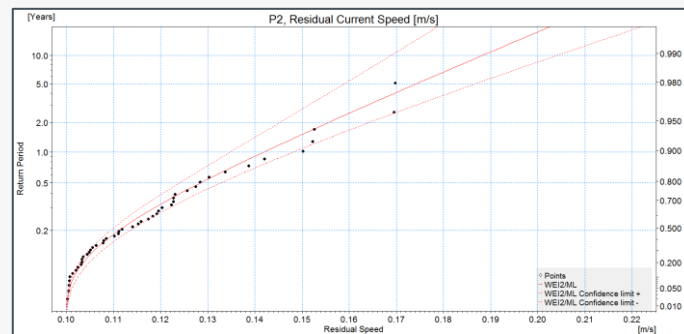
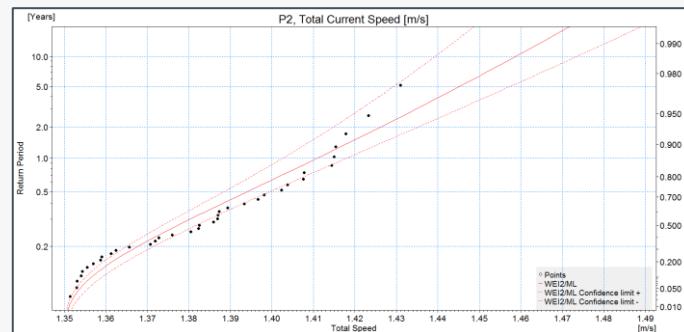
8. Data Analysis (6): Current

Extreme Value Analysis (EVA) of Current Speed

- Tidal analysis: Total CS $\rightarrow$ Tidal & Residual CS
- 3-parameter Weibull fit
- Location parameter fixed at threshold
- 1, 5 and 10 years return period
- Confidence bands by Monte Carlo simulations

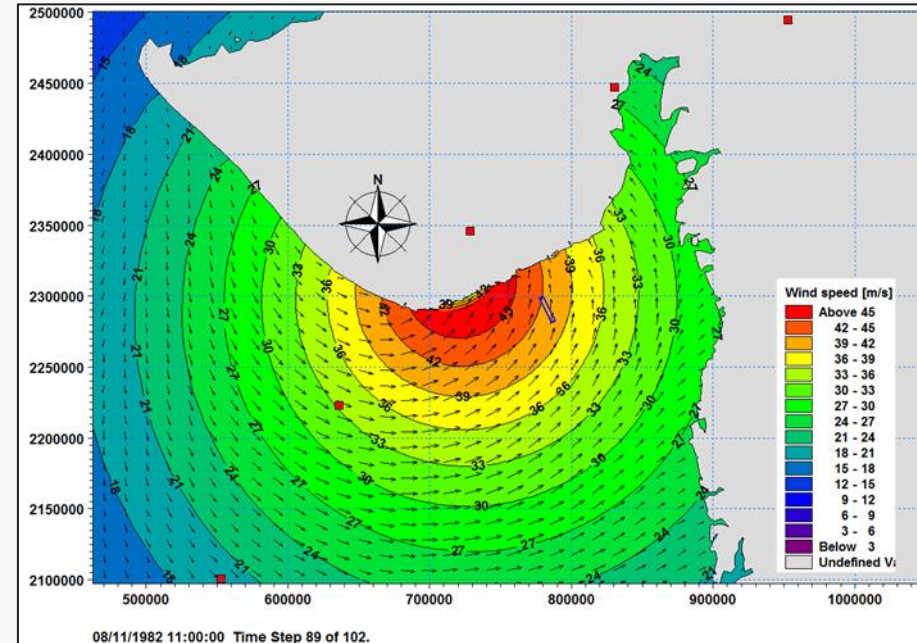
Total Current Speed [m/s]	Return Period [Years]		
	1	5	10
Central estimate	1.42	1.45	1.46
Standard deviation	0.01	0.01	0.02
Recommended value	1.43	1.46	1.48

Weibull fits

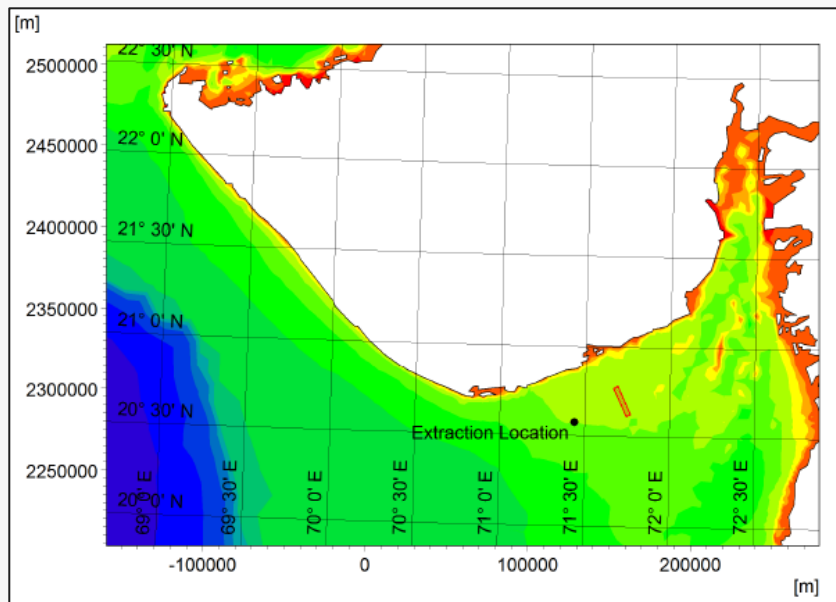


9. Cyclone Study (1)

- Assessment of extreme conditions with RP of 10, 50 and 100 years
- Connected to cyclones
- Very few cyclones at OWF site during hindcast period of 5 years
- Approach in COWI study:
 1. Cyclones during long period within 200 km from OWF site (1975-2015)
 2. Select most onerous cyclone
 3. Apply *Tropical Cyclone Risk Model* (TCRM) by Geoscience Australia to determine extreme wind speed
 4. Scaled synthetic cyclone
 5. Hindcast simulations
 6. Extract extreme events at OWF site



9. Cyclone Study (2)

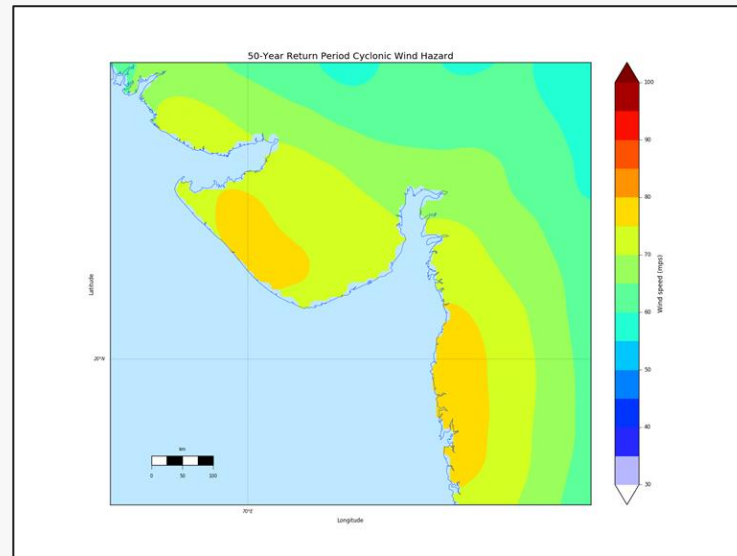


No	Year	Date	U _{max} (knots)	Place of passing	Wave height Hs(m) [20m]	Est. wind speed (m/s)
1	1975	19-24 Oct	80	Porbandar	6.4	19.5
2	1975	01-11 May	95	Off Karnataka	3.9	7.2
3	1977	13-22 Nov	110	Mangalore coast	3.5	4.6
4	1978	03-13 Nov	80	Gulf of Kutch	2.7	5.3
5	1979	13-17 Nov	40	Off Mumbai	3.1	12.0
6	1980	12-19 Nov	35	Off Karnataka	1.5	7.0
7	1981	25 Oct-03 Nov	60	Porbandar	4.3	13.2
8	1982	04-09 Nov	85	Porbandar	7.7	40.4
9	1985	28 May-1 Jun	50	Kutch coast	3.4	11.8
10	1989	07-13 Jun	35	Near Porbandar	2.1	11.3
11	1993	09-16 Nov	80	Gulf of Kutch	3.5	5.4
12	1995	11-18 Oct	50	Off Maharashtra	1.6	7.0
13	1996	15-25 Jun	65	Porbandar	7.4	31.8
14	1996	20-28 Oct	65	Porbandar	5.1	17.7
15	1998	01-09 Jun	105	Porbandar	7.0	20.5
16	1998	11-17 Dec	65	Off West Coast	2.8	5.6
17	1999	15-21 May	110	Kutch coast	5.5	12.2
18	2001	21-29 May	110	Kutch coast	5.5	12.1
19	2004	01-03 Oct	40	Off Porbandar	1.2	6.4
20	2007	21-26 Jun	50	Near Porbandar	0.7	7.9
21	2007	31 May-08 Jun	140	Offshore	3.1	5.8
22	2009	09-11 Nov	50	Maharashtra Coast	1.2	2.0
23	2010	31 May-06 Jun	125	Porbandar	2.7	10.0
24	2011	09-12 Jun	35	Veraval Coast	3.2	17.3
25	2014	25-30 Oct	115	Offshore	3.8	3.0
26	2014	10-13 Jun	55	Offshore	1.9	5.5
27	2015	07-11 Jun	55	Offshore	1.1	7.4

9. Cyclone Study (3)

Tropical Cyclone Risk Model (TCRM) by Geoscience Australia

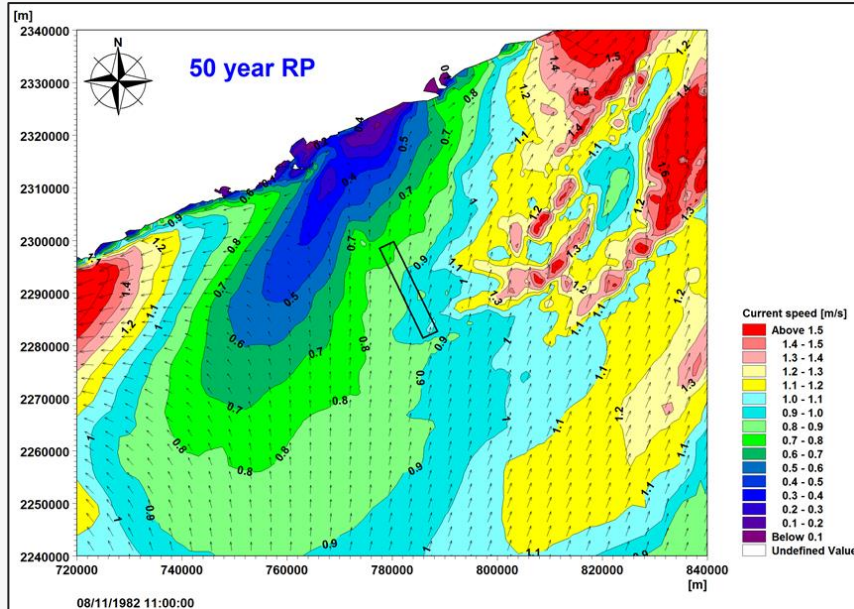
- Statistical and parametric model of tropical cyclone behaviours
- Simulate the impact of one or many tropical cyclone events
- It can be used to simulate many thousands of years of activity
- Determine the annual exceedance probability of cyclonic winds, or alternatively to examine the impact of a single event on a community
- Provides 3-sec gust speeds
- Open-source software application



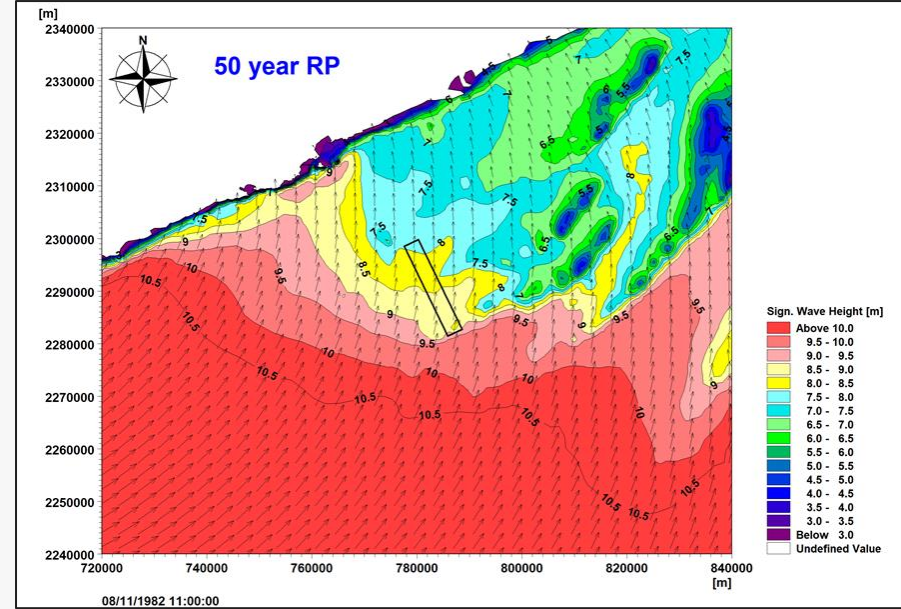
Return Period [Years]	Peak Wind Speed (10-minute average)	
	[m/s]	[knots]
10	50	97
50	59	115
100	62	122

9. Cyclone Study (4)

Current Speed



Significant wave height



10. Weather Windows (1)

- **Definition:** A continuous period of time in which a given parameter (H_{m0} or WS) does not exceed a given value. The **Weather Window (WW)** is given with respect to an **Operation Reference Period (ORP)** which is the time needed for a given operation
- The **presentation** of a WW during a given period of time (e.g. one calendar month) is given as the probability of total WW duration relative to the total duration of the period of concern
- **Minimum duration** of ORP analyses are defined as time intervals of 3, 6, 12, 18, 24, 36, 48, 72 and 96 hours, respectively
- **Threshold:** The significant wave height, H_{m0} , is smaller than 0.25m, 0.50m, 0.75m, 1.00m, 1.25m, 1.50m, 1.75m, 2.00m, 2.25m, 2.50m, 2.75m or 3.00m

10. Weather Windows (2)

Weather Window: 12 Hours

H _{m0} [m]	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
0.25	10.19	10.34	1.13	0.00	0.00	0.00	0.00	0.00	0.00	1.88	1.72	8.88	2.81
0.50	50.22	58.98	26.13	8.72	0.00	0.00	0.00	0.00	1.75	24.49	37.92	42.56	20.70
0.75	89.09	94.12	87.90	57.08	3.01	0.00	0.00	0.00	8.56	70.83	82.33	90.02	48.35
1.00	99.17	99.94	99.35	89.42	38.47	0.00	0.00	1.13	24.31	94.54	98.97	98.79	61.81
1.25	100.00	100.00	100.00	100.00	77.58	4.89	0.00	5.32	50.33	97.26	100.00	100.00	69.44
1.50	100.00	100.00	100.00	100.00	95.38	18.50	1.91	24.52	63.72	100.00	100.00	100.00	75.20
1.75	100.00	100.00	100.00	100.00	98.49	39.06	12.77	54.27	83.14	100.00	100.00	100.00	82.19
2.00	100.00	100.00	100.00	100.00	99.84	61.42	38.98	74.87	94.22	100.00	100.00	100.00	89.03
2.25	100.00	100.00	100.00	100.00	100.00	84.33	76.02	90.43	98.72	100.00	100.00	100.00	95.76
2.50	100.00	100.00	100.00	100.00	100.00	95.42	92.15	99.38	99.47	100.00	100.00	100.00	98.86
2.75	100.00	100.00	100.00	100.00	100.00	99.58	99.27	99.81	99.94	100.00	100.00	100.00	99.88
3.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

MINIMUM WEATHER WINDOW [Hours]

H _{m0} < 1.50m	0	3	6	12	18	24	36	48	72	96
January	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
February	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
March	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
April	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May	96.08	96.02	95.81	95.38	94.65	94.65	94.65	94.65	92.47	92.31
June	21.53	21.33	20.06	18.50	18.11	18.11	18.11	18.11	14.86	10.69
July	4.41	4.41	3.41	1.91	1.91	1.91	1.91	1.91	0.00	0.00
August	31.08	30.56	28.12	24.52	24.06	21.45	21.45	20.38	19.03	19.03
September	67.72	67.53	66.64	63.72	62.86	62.25	62.25	62.25	60.58	60.58
October	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
November	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
December	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

11. Summary

Results of FOWPI *preliminary metocean study for OWF in the Gulf of Khambhat* are documented in 3 reports:

- **FOWPI Metocean Study.** COWI Doc. No. A073635-014-001, 06/02/2017
- **FOWPI - Weather Windows for Installation.** COWI Doc. No. A073635-014-002, 31/01/2017
- **Metocean Data Requirements. Offshore Wind Foundations.** COWI Doc. No. A073635-014-003, 27/03/2017

Operational data based on a 5 year long hindcast by MIKE 21 models

Extreme data based on historical cyclones combined with extreme conditions from statistical model (TCRM)

Weather Windows given for planning of marine operations

12. Recommendations

- In order to update this preliminary metocean study report to a technical level usable for Detailed Design of foundations and WTG a series of **on-site measurements** of environmental data are needed. The measured data shall be used for validating the site-specific metocean conditions predicted by the numerical models at the actual wind farm site.
- On-site measurements of wind, wave and hydrodynamic data (i.e. water level and current data) during a period covering the monsoon season as well as outside the monsoon season are needed.
- The wave and hydrodynamic measurements can be carried out by means of a wave buoy with current-sensor or an ADCP placed at sea-bed while wind speed measurements e.g. can be made with a MEASNET calibrated first class cup anemometer. A **6-12 month continuous on-site measurement campaign** (in agreement with governing standards) with one or two recorders should be performed.
- Furthermore, **detailed bathymetric and geophysical surveys** should be carried out to support the detailed design and to resolve the wave transformation and flow pattern along the cable corridor and at the wind farm. The updated met-ocean study should also be based on a **detailed wind study**, as also required for WTG design or wind resource assessment.
- Based on detailed bathymetric surveys the **metocean study shall be updated** to be used for detailed design using the actual and confirmed bathymetric conditions in and around the site.

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Thank You!

