1. DESIGN ENVIRONMENT

1.1 Climate

The climate in Maldives is warm and humid, typical of the tropics. Long-term data is vailable for 5 weather stations across the Maldives, which are Hdh. Hanimaadhoo, K. Hulhulé, L. Kadhdhoo, Gdh. Kaadehdhoo and S. Gan. Data from the Maldives Meteorological Service (MMS) for the weather station at Hulhulé has been used to describe the climatic conditions of the project site as is the nearest station to Gulhifalhu – about 8 km away. The available data for Hulhulé spans from 1985 to 2016 – except for temperature data which is available from 1974 onwards.

The mean daily temperature varies between 24.1°C and 31.5°C and relative humidity varies from 73 percent to 85 percent. The annual average rainfall is approximately 1967 mm. Maldives receives plenty of sunshine throughout the year. Hulhulé receives 2809 hours of sunshine per year on average with very little variation (Standard Deviation < 100). There are observable differences in the climate between the northern and the southern atolls. The annual average rainfall in the southern atolls is higher than the northern atolls. In addition, greater extremes of temperature are also recorded in the southern atolls.

Key meteorological information from MMS is summarised in the table below.

Table 1: Key Meteorological Information of the Maldives (Maldives Meteorological Service, 2018)

Parameter	**Data**
Average Rainfall	9.1 mm/day in May, November; 1.1 mm/day in February
Maximum Rainfall	184.5 mm/day in October 1994
Average air temperature	30.0 °C in November 1973; 31.7 °C in April
Extreme Air Temperature	34.1 °C in April 1973;17.2 °C in April 1978
Average wind speed	3.7 m/s in March; 5.7 m/s in January, June
Maximum wind speed	W 31.9 m/s in November 1978
Average air pressure	1012 mb in December; 1010 mb in April

1.2 Monsoons

The climate of Maldives is characterised by the monsoons of the Indian Ocean with monsoonal wind reversal significantly affecting weather patterns. Two monsoon seasons are observed: the Northeast (Iruvai) and the Southwest (Hulhangu) monsoon. The parameters that best distinguish the two monsoons are wind and rainfall patterns. The southwest monsoon is the rainy season while the northeast monsoon is the dry season. The southwest monsoon occurs from May to September and the northeast monsoon is from December to February. The transition period of southwest monsoon occurs between March and April while that of northeast monsoon occurs from October to November.

1.3 Winds

The winds that occur across Maldives are mostly determined by the monsoon seasons. The two monsoons are considered mild given that Maldives is located close to the equator. As a result, strong winds and gales are infrequent although storms and squall

lines can occur, usually in the period May to July. During stormy conditions, gusts of up to 111 km/hr have been recorded at Malé.

Wind direction and speeds show considerable uniformity in the Maldives since the records began in Hulhulé Island[1]. Figure 1 and Figure 2, which show the frequencies of predominant wind directions in Hulhulé, show no discernible change in the annual wind frequencies. Wind speed is usually higher in central region of Maldives during both monsoons, with a maximum wind speed recorded at 31.9 ms-1 for the period 1975 to 2010. Mean wind speed is highest during the months May and October in the central region. Wind analysis indicates that the monsoon is considerably stronger in central and northern region of Maldives compared to the south [2]

Besides the annual monsoonal wind variations there are occasional tropical climatic disturbances (tropical storms or low intensity tropical cyclones) in the central region which increases wind speeds up to 110 km/h, precipitation of 30 to 40 cm over a 24 hour period and storm surges up to 3 m in open ocean (UNDP, 2006).

Table 5.2 summarises the wind conditions in central Maldives throughout a year. Medium term meteorological data from Maldives Meteorological Services located in Hulhulé (Figure 1 and Figure 2 and Figure 3) and findings from long-term Comprehensive Ocean-Atmosphere Data Set (COADS) are used in this analysis.

Table 2: Summary of General Wind Conditions from National Meteorological Centre

Season	**Month**	**Wind**
NE - Monsoon	December	Predominantly from NW-NE. High Speeds from W
	January	
	February	
Transition Period 1	March	From all directions. Mainly W. High Speeds from W.
	April	
SW - Monsoon	May	Mainly from W. High Speeds from W.
	June	
	July	
	August	
	September	
Transition Period 2	October	Mainly from W. High Speeds from W
	November	

Figure 1 shows the monthly frequncies of wind direction recorded at Hulhulé. The transition between monsoon can be seen in the change in predominant wind direction from the west to east and north east.

[1] Naseer, A. (2003). The integrated growth response of coral reefs to environmental forcing: morphometric analysis of coral reefs of the Maldives. Dalhousie University Halifax, Nova Scotia.
[2] Naseer, A. (2003). The integrated growth response of coral reefs to environmental forcing: morphometric analysis of coral reefs of the Maldives. Dalhousie University Halifax, Nova Scotia.

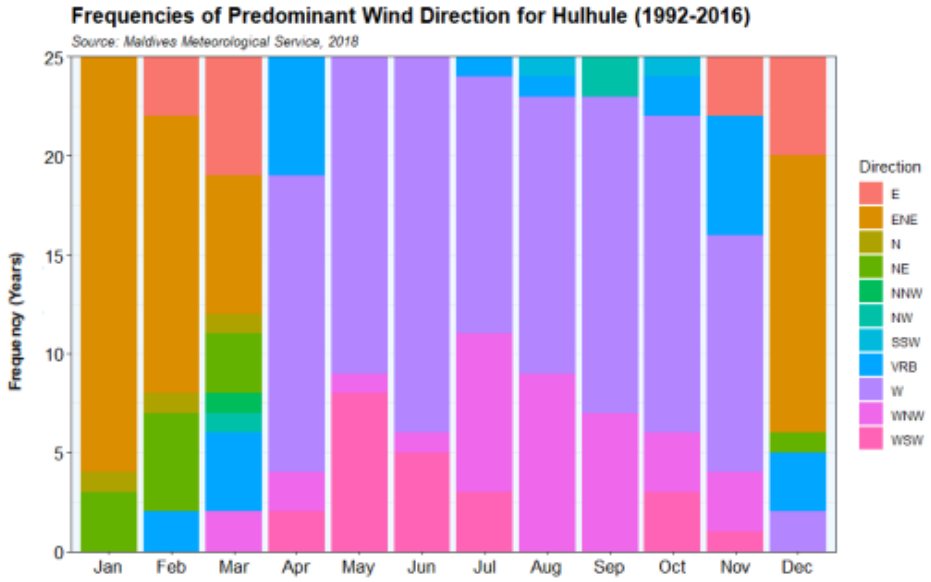

Figure 1: Monthly Frequencies of Wind Direction in Hulhulé (MMS, 2018)

Figure 2 shows the monthly predominant directions through the years 1992 to 2016. The distribution of wind direction between the western and eastern and north eastern directions have been fairly uniform.

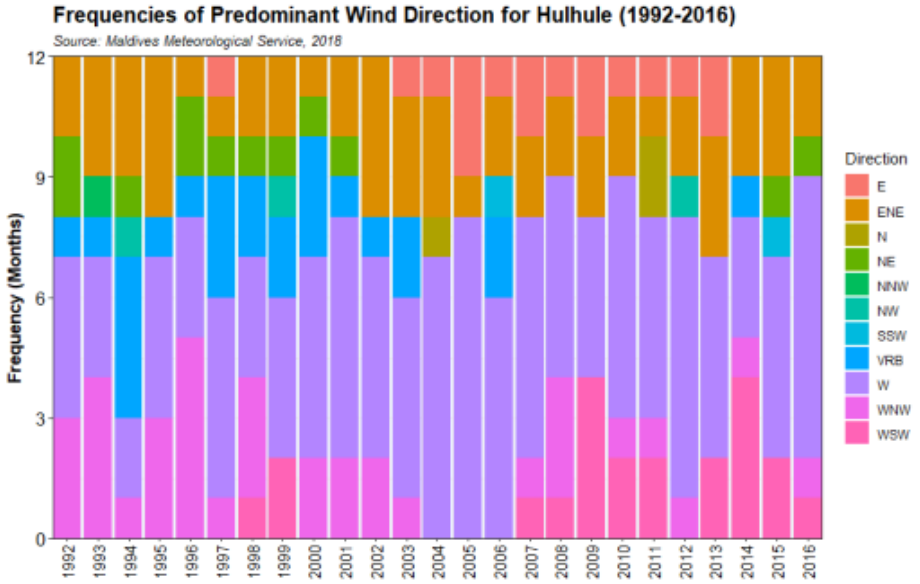

Figure 2: Yearly frequencies of predominant wind direction in Hulhulé

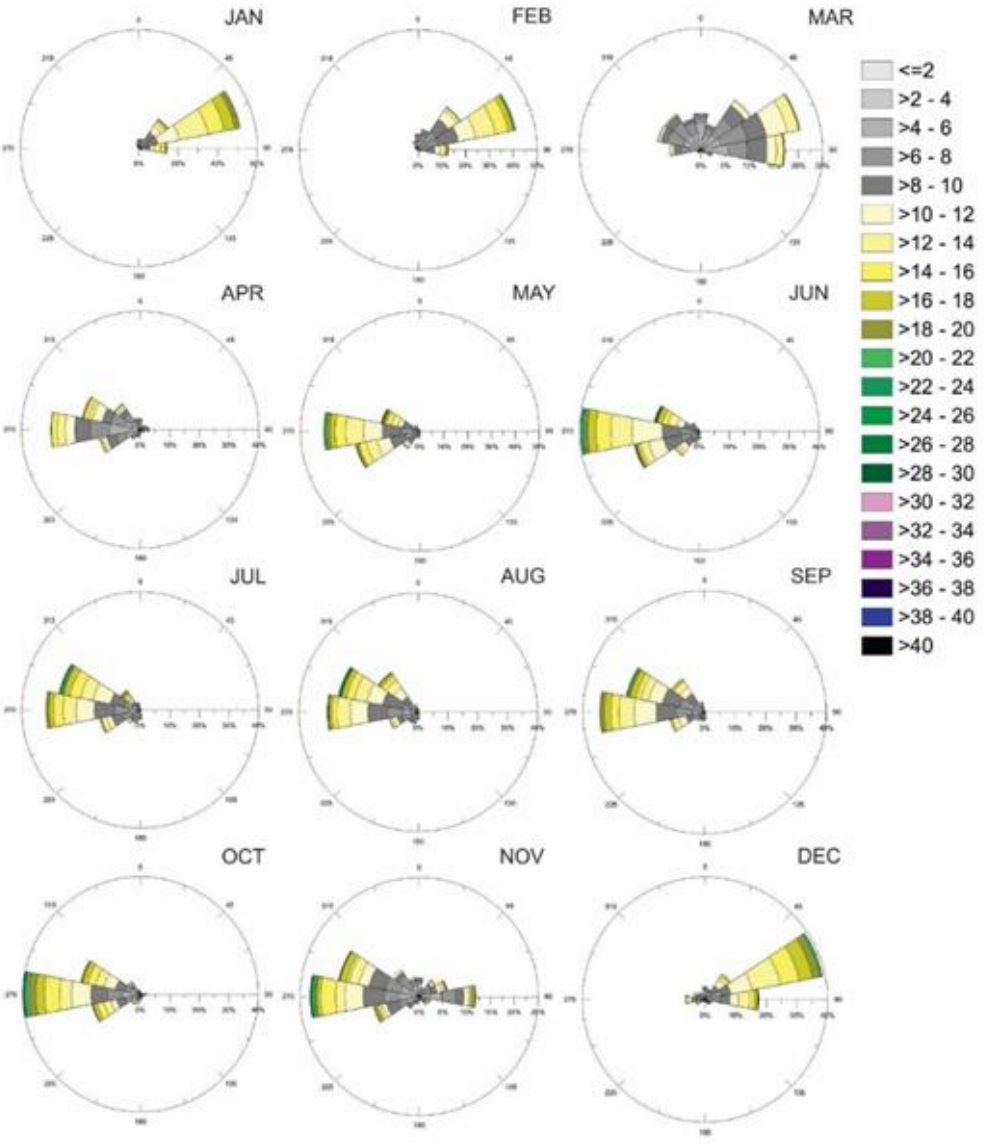

Figure 3: Average wind rose central region (Source: NMS, January 1998 to December 2015)

June and July, along with January, are the windiest months at Hulhulé, with a mean wind speed of 17 km/hr. The strongest winds recorded at Hulhulé has also been during these two months. The transition into the South-Western monsoon from the North-Eastern monsoon occurs in March and is indicated by winds which approach from variable directions (Figure 1).

Wind rose for Hulhulé Island is presented in Figure 3. Monthly average wind speeds observed from the wind rose analysis shows that the wind direction changes abruptly from NE to W on April and a clear transition period from W to NE monsoon is observed in November which extends to December as well. The highest maximum wind speeds occur during July and January to March are generally the calmer months.

Looking at the frequency plot data and wind rose plots; it was observed that the mean wind speed had gone as high as 36 kn towards the WNW direction. In general, the strongest winds occur from WSW, W and WNW directions. Winds from the south and SE as well as north were less prevalent and with comparatively low speeds. Majority of the times, winds occur at a speed of 4 to 14 kn which is generally known as light to moderate breeze.

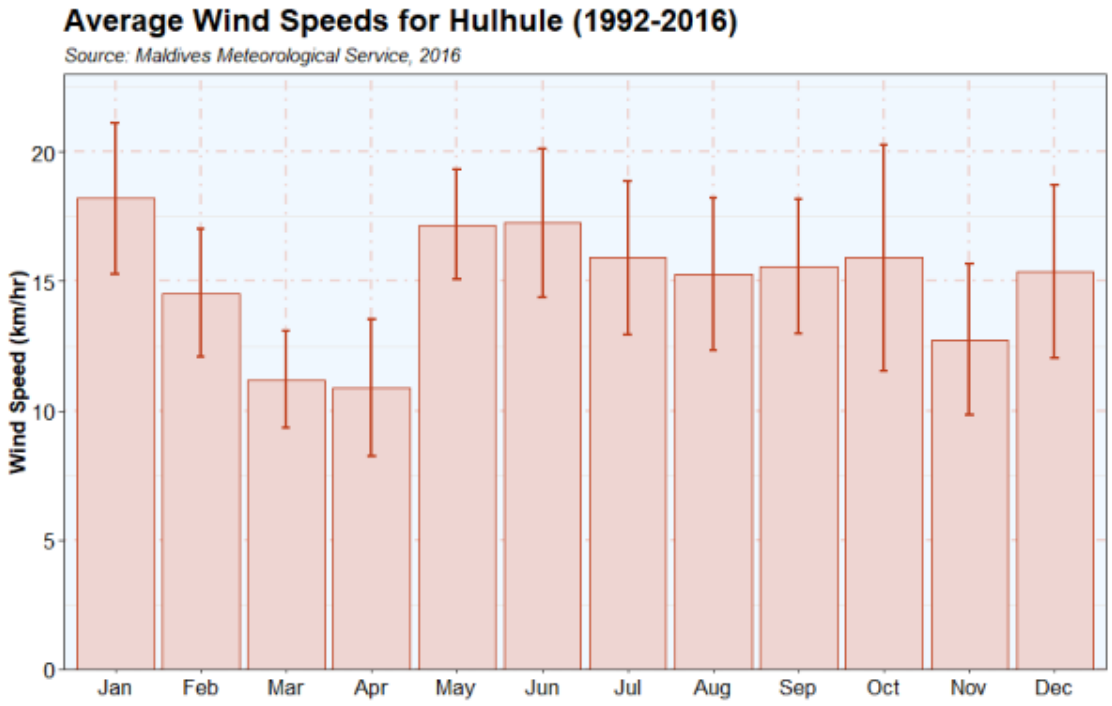

Figure 4: Mean daily wind speed and direction recorded at Hulhulé by Maldives Meterological Service (1992-2016)

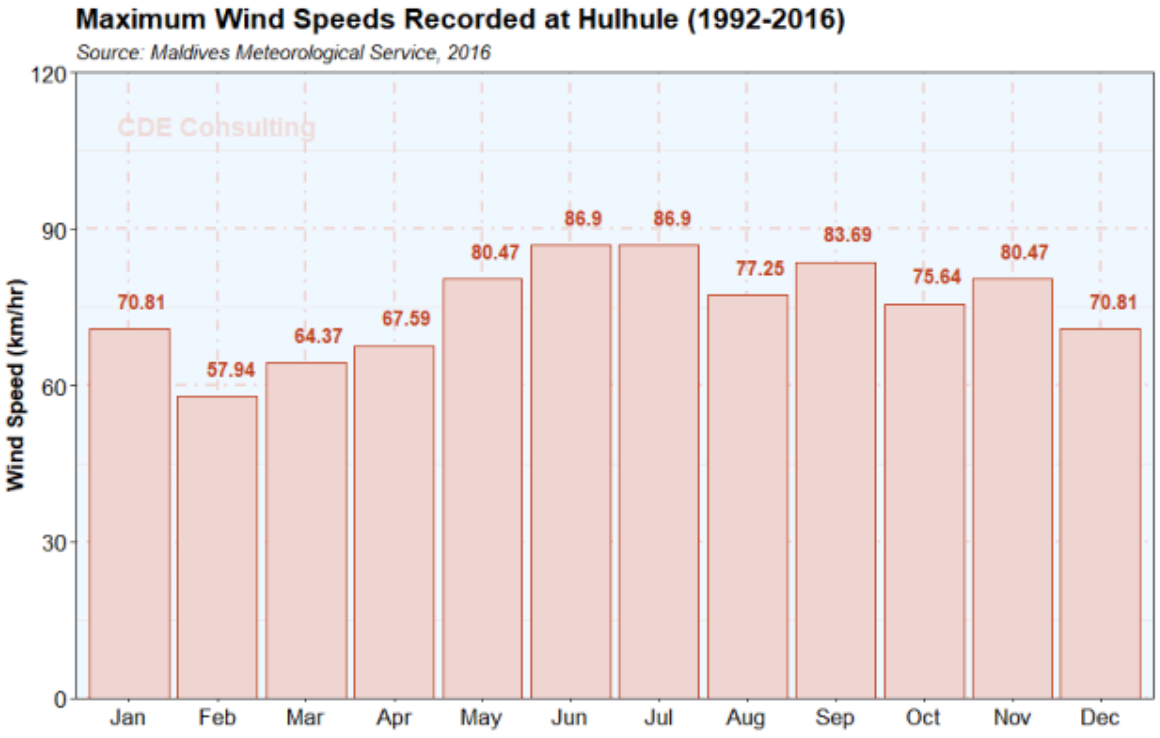

Figure 5: Maximum wind speeds recoded at Hulhulé from 1992 – 2016

1.4 Waves

There are two major types of waves observed along the islands of Maldives. The first type is wave generated by local monsoon wind with a period of 3-8 seconds and the second type is swells generated by distant storms with a period of 14-20 seconds[3]. The local monsoon predominantly generates wind waves, which are typically strongest during April-July in the southwest monsoon period.

Information on the swells around Maldives is limited but there have been a few studies carried out around Male'. Wave data for Male' that were recorded for the period between June 1988 and January 1990 revealed that the maximum significant wave height (Hs) recorded for the month of June 1989 was 1.23m with a mean period (Tm) of 7.53s. For the month of July 1989 maximum recorded Hs was 1.51m and the corresponding Tm was 7.74s. In June and July 1989 mean wave periods were 5.0 – 9.0s and the peak wave periods within 8.0 – 13.0s. Wave data for the period between September 1988 and July 1989 shows a probability of exceedance of Hs = 1.0 m was approximately 0.1 and of Hs = 1.5 m was approximately 0.0015 based on the wave data of period September 1988 to July 1989. The wave climate in Male' region is generally higher in the months of June, July and August with a predominant wave direction of S (180º)[4]. During October-December the waves have a shorter period with wave directions varying from S and W (180 º -270 º). It is estimated that the maximum wave height outside the flat reefs can reach more than 3m, whereas on the flat reef areas the wave height can reach from 0.6 to 1.2 meters (maximum).

The wave roses on the Eastern and Western side of the Maldives are presented in Figure 6. On the Eastern side of the Maldives, Westerly swells are uncommon due to the sheltering of the Maldivian Atolls. North-Easterly waves are typically locally generated waves driven by local wind conditions and generally have short periods of less than 10 seconds Figure 6. South Westerly and Southerly waves in comparison are generated in the Southern Indian Ocean and have longer periods of up to 24 seconds Figure 6.

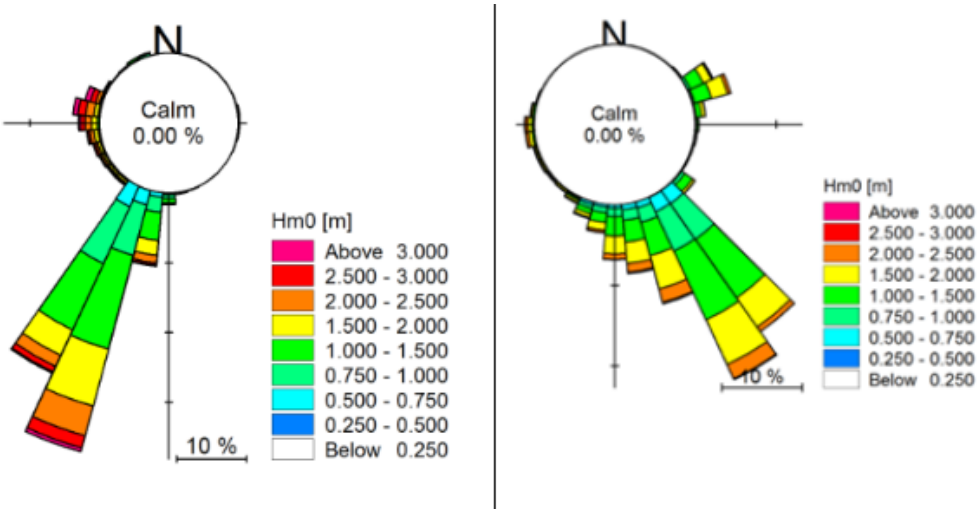

Figure 6: Open ocean wave rose for Western site Ari Atoll and Eastern Side of North Malé Atoll[5]

On the Western side of the Maldives, Easterly waves are uncommon due to the sheltering of the Atolls. South-Westerly waves are generated in the Southern Indian Ocean and are typically decoupled from local weather patterns and have long periods Figure 5. Westerly and North Westerly waves are locally generated and linked to strong monsoon winds.

Waves studies around Maldives have also identified the presence of swell waves approaching

3 Binnie Black & Veatch. (2000). Environmental/Technical study for dredging/reclamation works under Hulhumalé Project - Final Report.
4 Kench, P. S., Brander, R. W., Parnell, K. E., & McLean, R. F. (2006). Wave energy gradients across a Maldivian atoll: Implications for island geomorphology.
5 CDE (2020) EIA for the proposed dredging, land reclamation, and revetment work at Gulhifalhu

predominantly from a southwest to a south easterly direction Figure 6.

1.5 Storm Surge

Storm surge may increase the water level due to: the effect of atmospheric pressure variations. A water level variation of 10 cm occurs with a pressure variation of 10 hPa and wind effects, especially in shallow water areas.

1.6 Risk of cyclones / hurricanes

The islands of the Maldives are less prone to tropical cyclones. The northern islands of the country have been affected by weak cyclones that formed in the southern part of the Bay of Bengal and the Arabian Sea. The number of cyclones directly crossing the Maldives is small. Only 11 cyclones crossed the islands over the entire span of 128 years between 1877 and 2004[6]. All of these events were category 1 cyclones.

Most of the cyclones crossed the Maldives north of 6.0°N and none of them crossed south of 2.7°N during the period. All the cyclones that affected the Maldives were formed during the months of October to January except one, which formed in April. The Maldives have not been affected by cyclones since 1993.

In the northern islands, the probable maximum storm tide due to cyclones has been estimated to be around 1.82 m (storm surge of 0.84 m) for a return period of 100 years. This storm surge was computed taking into account probable maximum winds and probable maximum pressure drops.

1.7 Sea Level Rise

There is large inter-annual variability in sea level as well as a longterm trend of increasing relative sea level (Figure 8) The observed long-term trend in sea level is 1.7 mm/yr[7]. This value is towards the upper end of the predicted global sea level rise values as described in the Intergovernmental Panel on Climate Change (IPCC) report[8]. Extreme sea levels are also present in the mean hourly sea-level data from Hulhulé which shows a longterm trend of 7 mm/yr[9]. These values suggest abnormal storm or swell activities which has the potential to cause flooding in low lying islands.

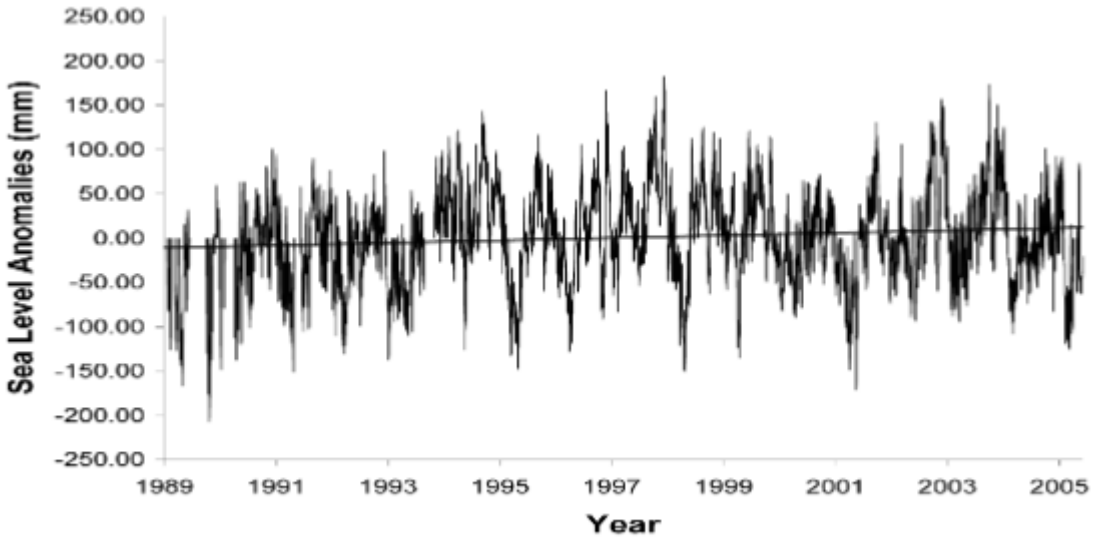

Figure 7: Daily mean values of sea level for Hulhulé (1989 to 2005), relative to mean sea level. Also shown is the linear trend in sea level over the same period (Hays, 2006).

[6] UNDP (2006). Developing a Disaster Risk Profile for Maldives. Malé, United Nations Development Programme and Government of Maldives.
7 Hays, J. (2006). Climate Risk Profile for the Maldives
8 IPCC. (2007). Climate Change 2007: Synthesis Report. https://doi.org/10.1038/446727a
9 Hays, J. (2006). Climate Risk Profile for the Maldives

1.8 Criteria for MET Alerts and Warnings

Most of the days the sea is moderate. During severe weather conditions, the MET office issues warnings (White, Yellow, Orange, and Red).

Hazard	CAP Categories of Severity			
	Minor (Alert level 1, WHITE)	Moderate (Alert level 2, YELLOW)	Severe (Alert level 3, ORANGE)	Extreme (Alert level 3, RED)
Heavy Rain and Flood	50 mm in 1hrs or 80 mm in 6 hours	70 mm in 1hrs or 100 mm in 6 hours	90 mm in 1hrs or 120 mm in 6 hours	180 mm in 6 hours
Thunderstorms (TS)	Significant TS reported and evident from satellite/Radar/LDN	Moderate TS observed or evident from satel-lite/Radar/LDN.	Severe TS observed or evident from satellite/ Radar/LDN.	---
Wind and Seas	19-24 mph (past 3 hrs) or 22 – 27 mph (past 1hr), or forecast to meet this condition	25-30 mph (past 3 hrs) or 28 – 35 mph (past 1hr), or forecast to meet this condition	34-40 mph(past 3 hrs) or 36 – 42 mph (past 1hr), or forecast to meet this condition	>40 mph (past 3 hrs) or >42 mph (past 1hr), or forecast to meet this condition
Squalls (Frequent Gust)	50 - 54 mph	55 - 62 mph	63 - 69 mph	above 70 mph
Swell & Tidal Waves (observed or forecast)	Observed or forecast (minor impact)	Observed or forecast (affect at least 5 islands)	Observed or forecast (affect at least 10 islands)	Observed or forecast (extreme impact based)
Tropical Cyclone (TC)	RSMC declare TC center in the box within lat' S5-N12, lon' E66-E81	TC track towards Maldives and expect to cross Maldives atolls in next 24hr	TC track towards Maldives and expect to cross Maldives atolls in next 12hr	TC track towards Maldives and expect to cross Maldives atolls in next 6hr
Earthquake occured	Magnitude >6 within 400km of Maldives EEZ. Or mag>7 in Indian Ocean within 4000km of Maldives EEZ	Magnitude >7 within 400km of Maldives EEZ. Or mag>8 in Indian Ocean within 4000km of Maldives EEZ	Magnitude > 8 within 400km of Maldives EEZ. Or mag>9 in Indian Ocean within 4000km of Maldives EEZ	Magnitude >9 within 400km of Maldives EEZ
Tsunami	Magnitude >8 in Indian Ocean within 4000km of Maldives EEZ. Or confirmation of Indian ocean wide Tsunami of low impact to Maldives	Magnitude>9 in Indian Ocean within 4000km of Maldives EEZ. Or confirmation of Indian ocean wide Tsunami of moderate impact to Maldives	Confirmation of Indian ocean wide Tsunami of high impact to Maldives	Confirmation of Indian ocean wide Tsunami of extreme impact to Maldives

The vessel should be operating at least in a yellow alert sea (moderate sea/sea state 6-7 on Beaufort scale) which covers most of the days. Severe and extreme weather conditions should be used for maintenance or crew rest. Maximum for design : Beaufort scale 8