# WAVE CLIMATE IN GO CONG AND U MINH

## 1. Introduction

The study is to understand the mechanism of the erosion/accretion process under the effects of waves, and then to find the measures in order to protect the Go Cong and U Minh coastal zones from erosion.

## 2. Tasks and objectives

- Develop the wave model (Tomawac) to simulate the wave conditions in East sea and in Southwest sea of Viet Nam, and in the coastal area of Go Cong and U Minh over a period of 8 years (2009 – 2016)
- Analyze the wave characteristics to understand the wave climate over the study areas

## 3. Activities

- Collect the bathymetry data and wind data for numerical model (Tomawac)
- Set up the Tomawac model and calibrate to simulate the wave conditions from 2009 to 2016 in Go Cong and U Minh coastal zones
- Plot the wave roses at 6 locations along the Go Cong and U Minh coastlines
- Analyze the statistics of wave height, wave period and wave direction and find the characteristics of the wave climate over the study areas

## 4. Results and deliverables

### a. Model set up and calibration

**Data input**

- *Bathymetry data:* The bathymetry data with the interval grid of 30 arc-second (925m) for East Sea and West South Sea was collected from GEBCO (General Bathymetric Chart of Ocean) data-base. In the study areas (Go Cong and U Minh coastal zones), the bathymetry data was collected from the measured data (2016) provided by LMDCZ project.
- *Wind data*: Wind field data in East Sea and West South sea was collected from NOAA with the global 30 arc-minute (55km) interval grid. The wind field is as the driven force to generate the wave.

**Model setup**

- Tomawac model was applied to simulate the wave propagation in East Sea and in the study areas including Go Cong coast and U Minh areas. The computed domain covers the whole East Sea. There are 2 computed grids. The grid for Go Cong includes 11263 nodes and 21642 elements, the size of grid ranges from 500m to 40km (corresponding to coastal zone and offshore area). The grid for U Minh includes 32544 nodes and 64046 elements, the size of grid ranges from 500m to 25km (corresponding to from coastal zone to offshore area).
- Boundary conditions for wave model were set as closed boundary in computed domain, that means no any wave boundary condition. Wind speeds varying with the space and time were input to model all over the computational grids for wave generation.

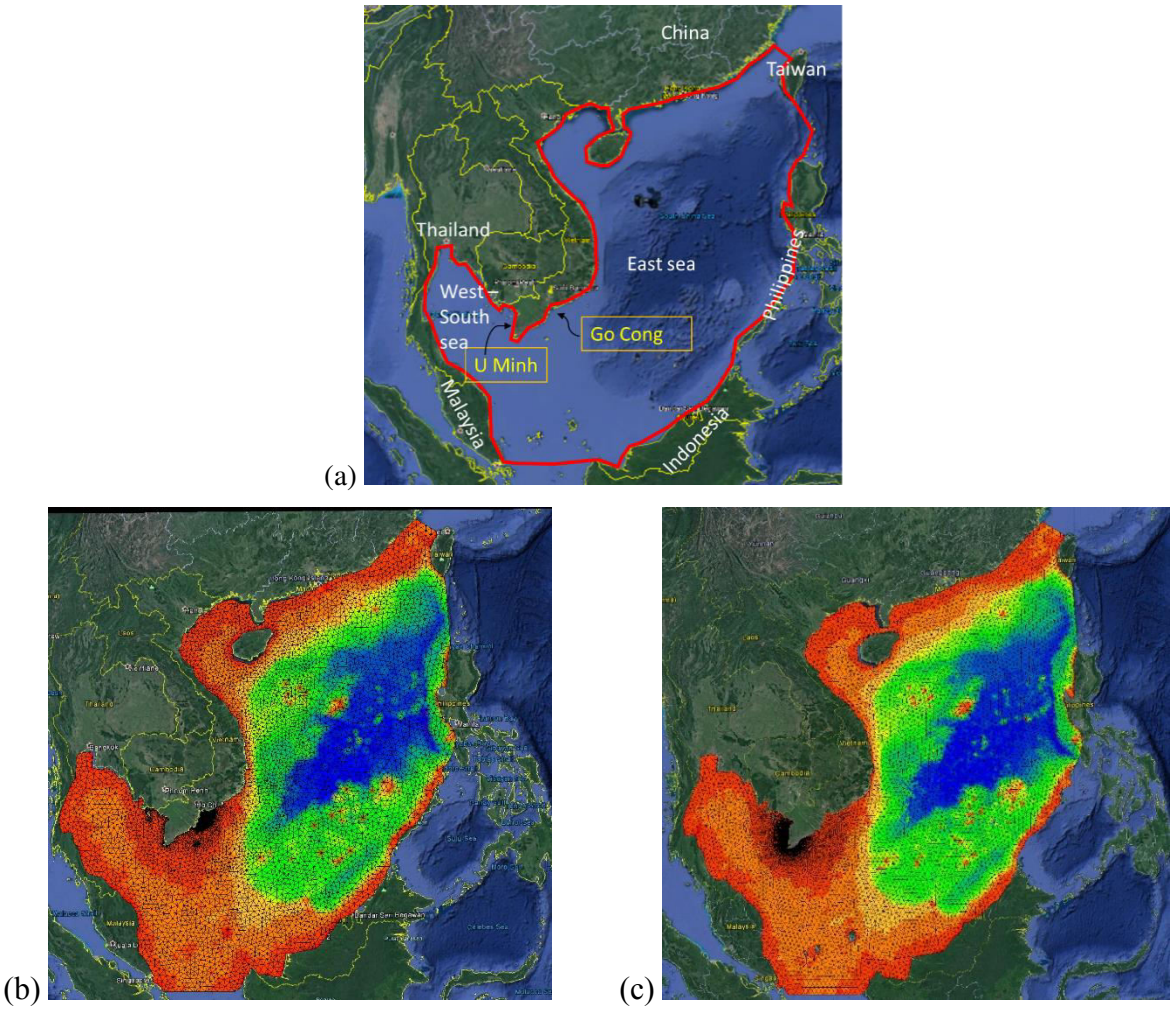


Figure 1. limits of the computational domain (a) and computing mesh for the East sea and Go Cong coastal zone (b) and for the East sea and U Minh coastal zone (c).

**Model calibration and validation**

The wave model was calibrated and verified by using the observed wave heights provided by the LMDCZ project. Two points, GCO1 in Go Cong coastal zone and UMO1 in U Minh coastal zone, were used to compare with the observed wave data. The coordinates of GCO1 and UMO1 are (106.880062°,10.268189°) and (104.677830°,9.314954°) respectively. There are 2 periods for calibrating and verifying wave model, the first period of calibration is 16 days for Go Cong (from 16th Oct to 31th Oct 2016) and 9 days for U Minh (from 16th Oct to 24th Oct 2016), the second period of validation is 16 days for Go Cong (from 24th Feb 2017 to 11th Mar 2017) and 16 days for U Minh (from 25th Feb 2017 to 12th Mar 2017). From Fig.3 to Fig.14 show the comparisons between the computed results and observed data of GCO1 and UMO1 (presented in Figure 2). The error index of RMSE, ME, SD and SI were used to evaluate the accuracy degree of model. The values of error index are given in table 1 and it is found that the model results are good for application.

Besides the observed wave data at the fixed station (GCO1, UMO1), a mobile station was used to measure the wave along the coast, from Go Cong to U Minh. The points where the mobile station collects wave data are shown in Fig.15. The comparison of observed wave data from the mobile station and computed results are presented in Fig. 16 and Fig.17.

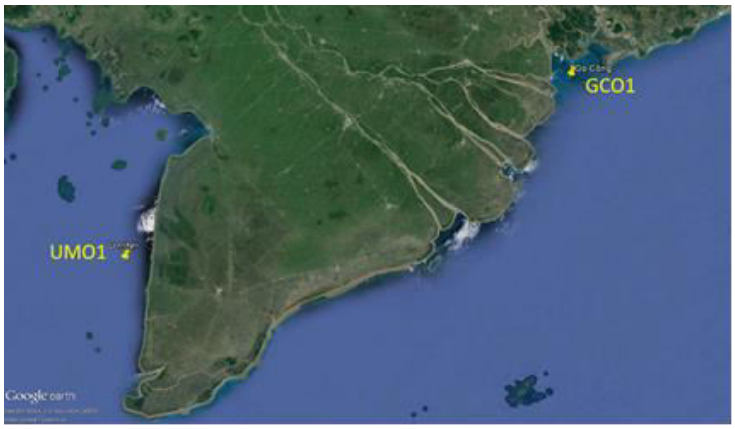


Figure 2. Location of 2 points for Tomawac model calibration and validation

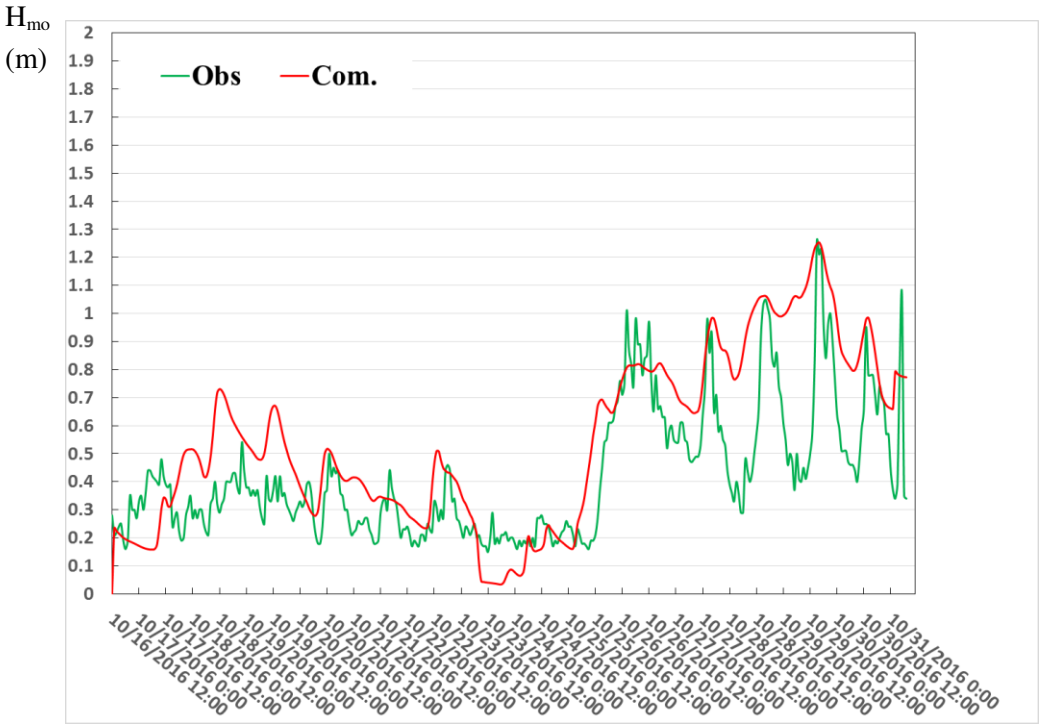


Figure 3. Comparison between computed and observed significant wave height $H_{m0}$ (m) at point GCO1 from 16/10 - 31/10/2016

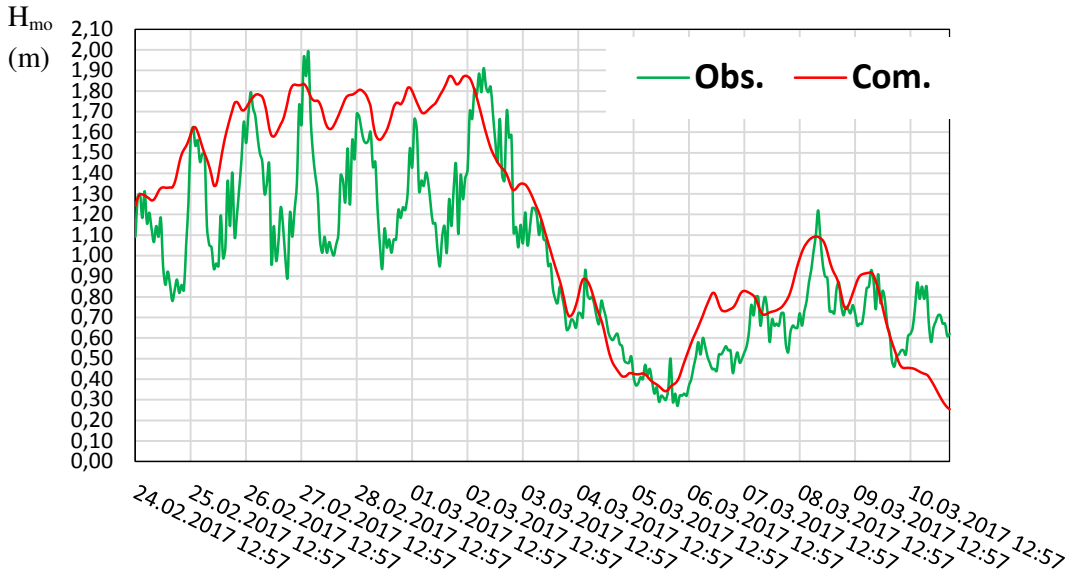


Figure 4. Comparison between computed and observed significant wave height $H_{m0}$ (m) at point GCO1 from 24/2 - 11/3/2017

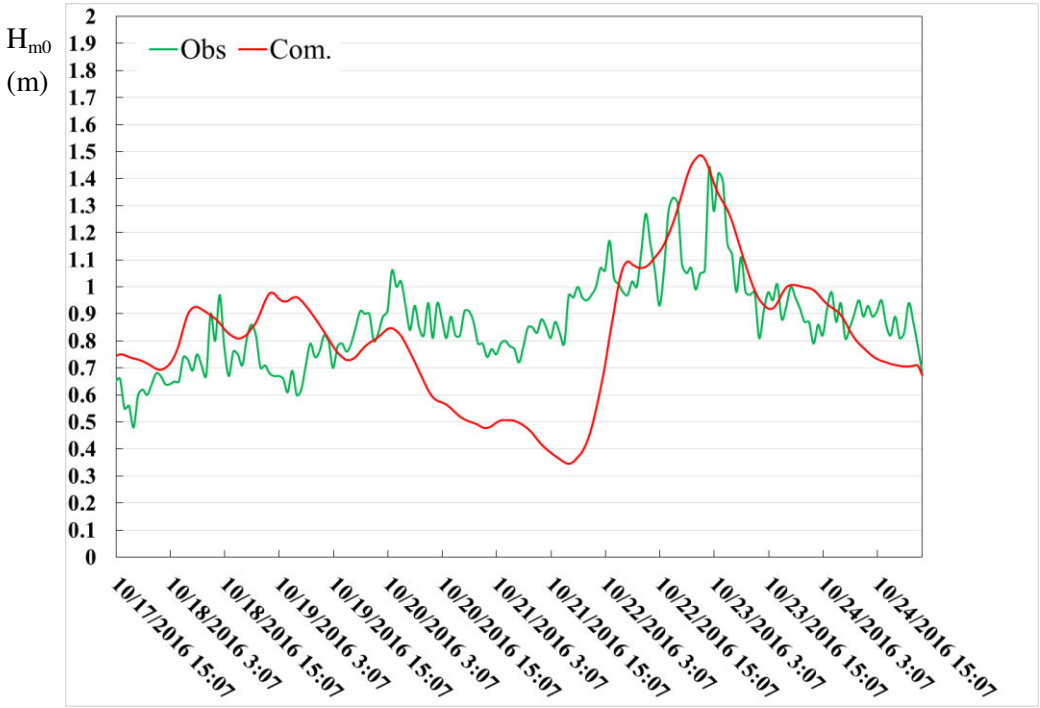


Figure 5. Comparison between computed and observed significant wave height $H_{m0}$ at point UMO1 from 16/10 - 24/10/2016

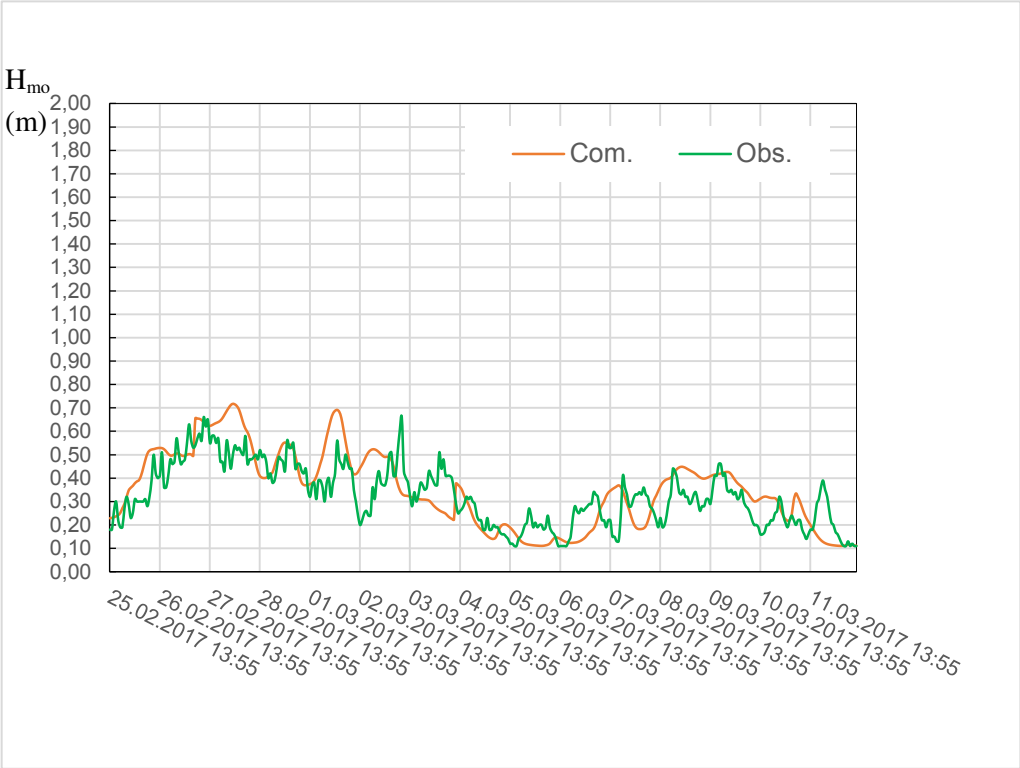


Figure 6. Comparison between computed and observed significant wave height $H_{m0}$ at point UMO1 from 25/2 - 12/3/2017

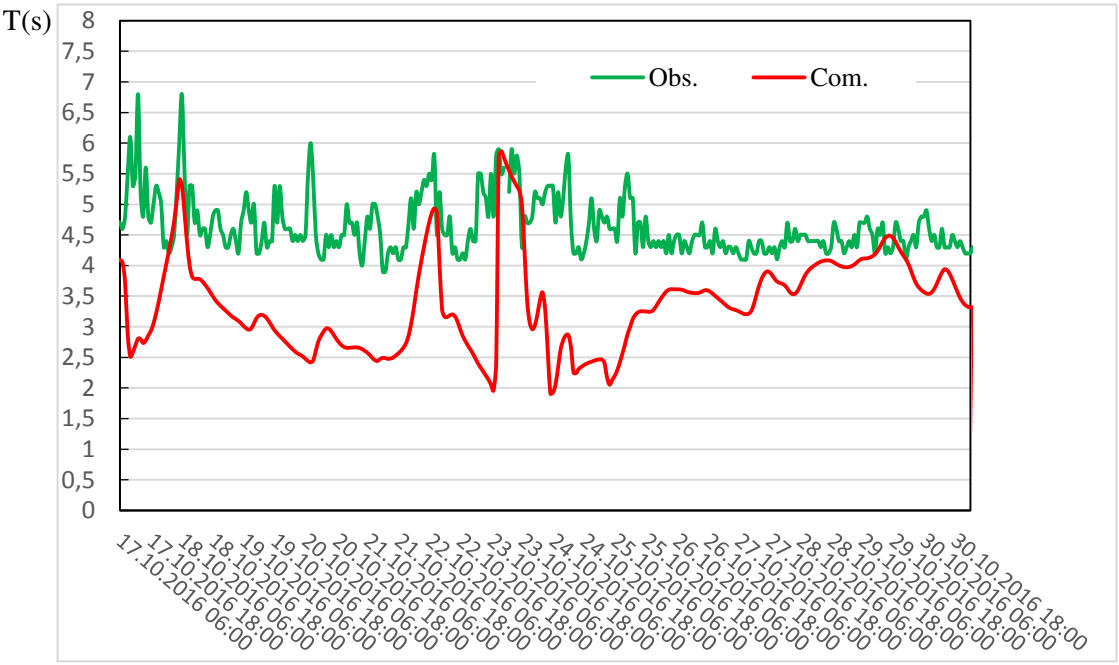


Figure 7. Comparison between computed and observed wave period T(s) at point GCO1 from 16/10 - 31/10/2016

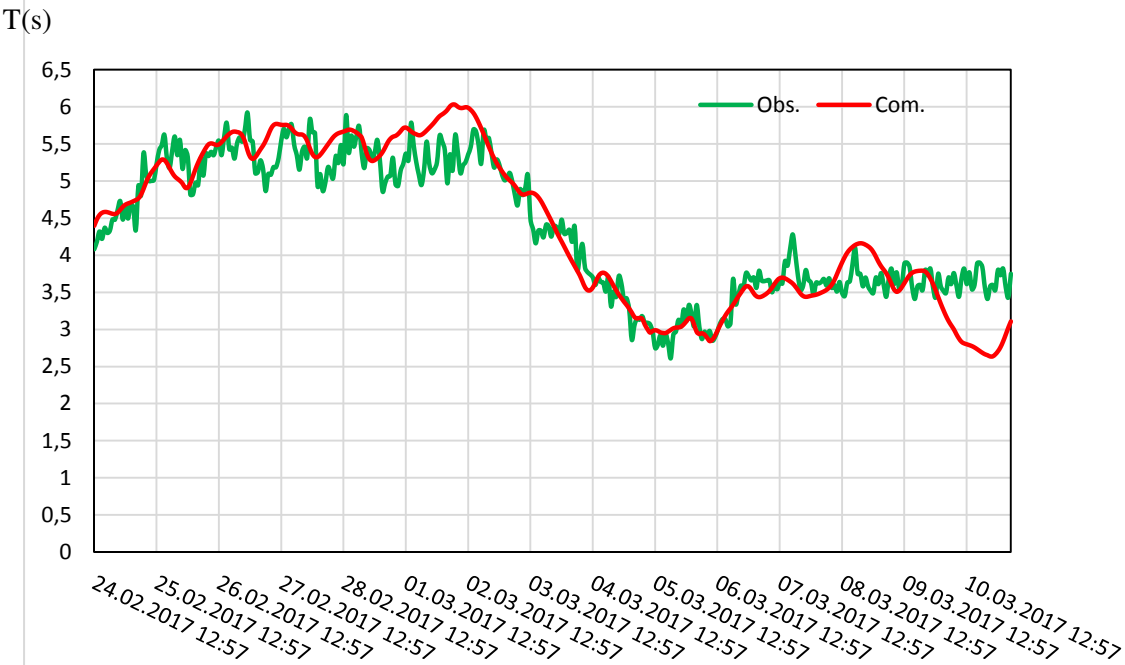


Figure 8. Comparison between computed and observed wave period T(s) at point GCO1 from 25/2 - 12/3/2017

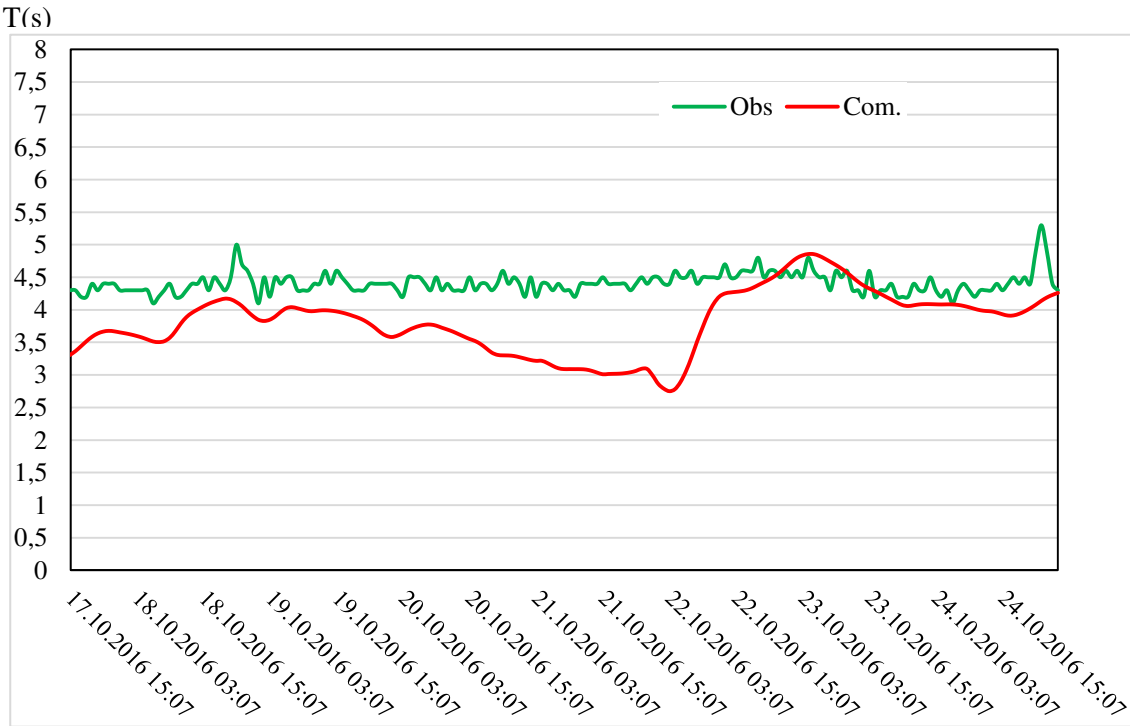


Figure 9. Comparison between computed and observed wave period T(s) at point UMO1 from 16/10 - 31/10/2016

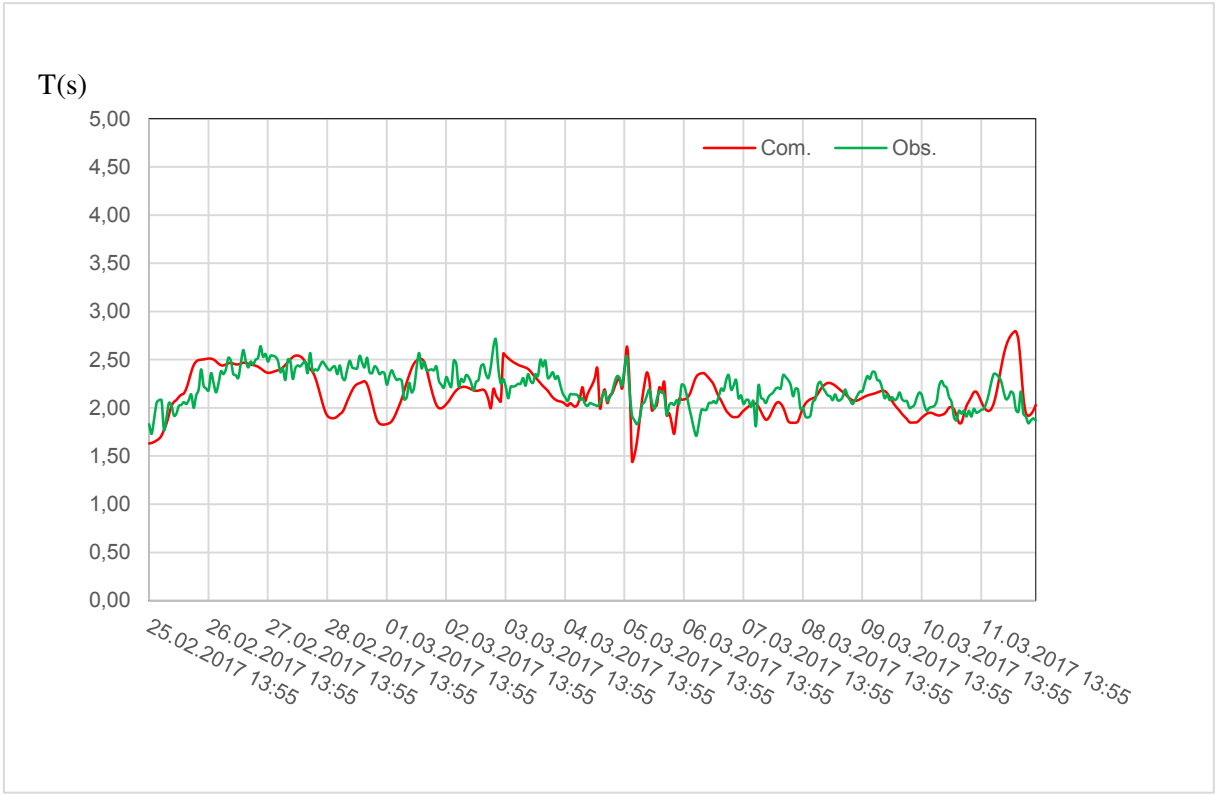


Figure 10. Comparison between computed and observed wave period T(s) at point UMO1 from 25/2 - 12/3/2017

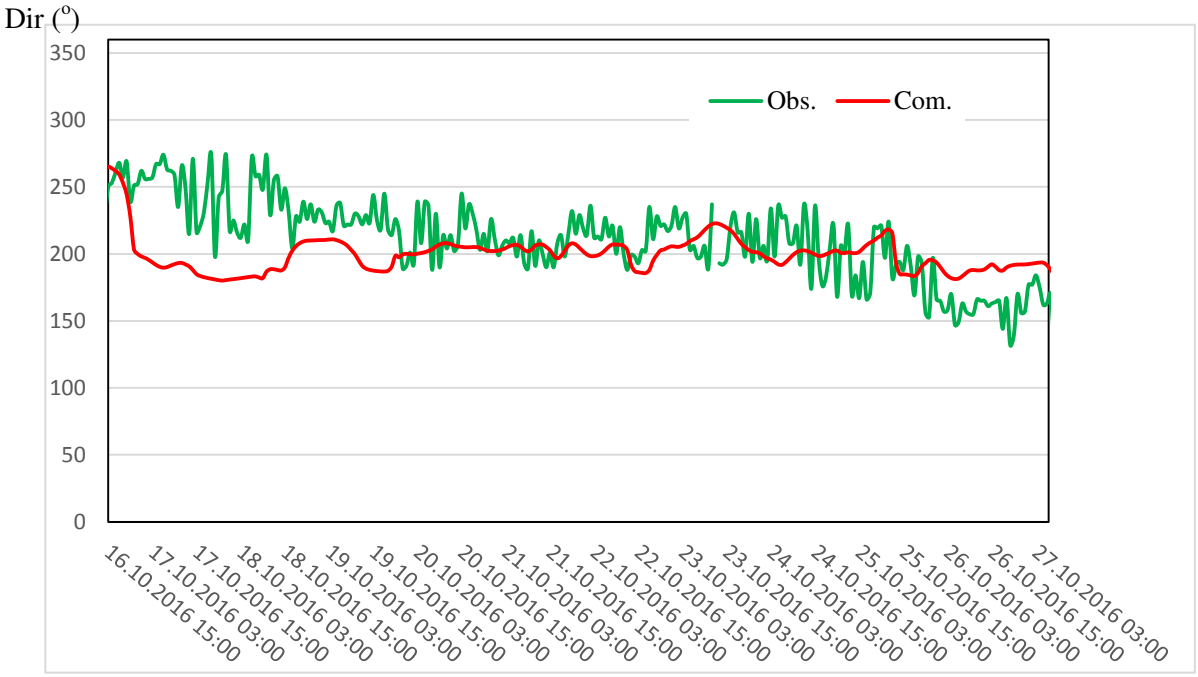


Figure 11. Comparison between computed and observed wave direction Dir(°) at point GCO1 from 16/10 - 31/10/2016

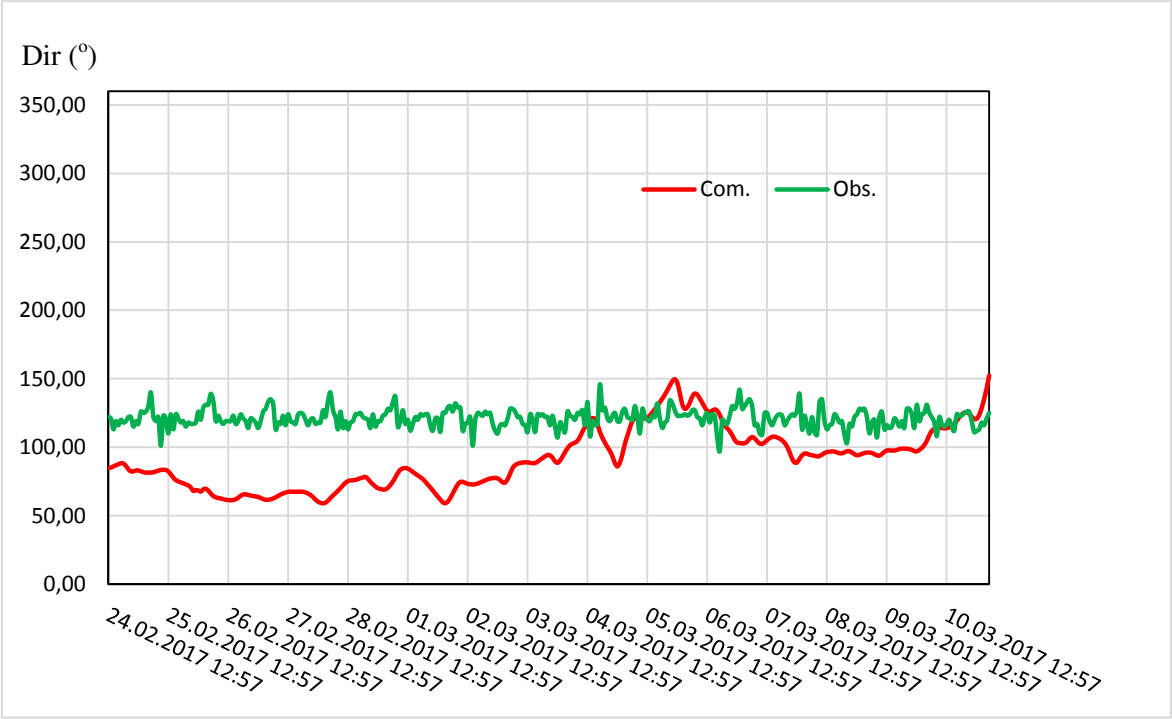


Figure 12. Comparison between computed and observed wave direction Dir(o) at point GCO1 from 25/2 - 12/3/2017

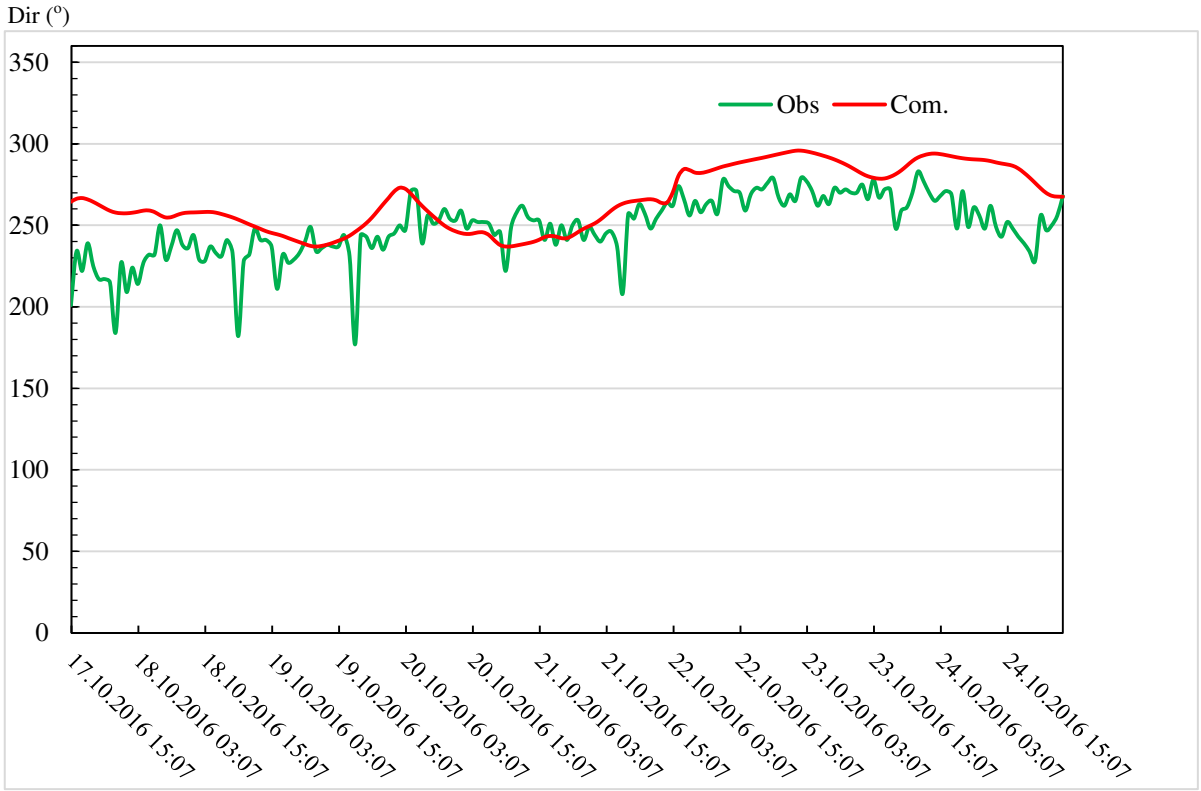


Figure 13. Comparison between computed and observed wave direction Dir(o) at point UMO1 from from 16/10 - 31/10/2016

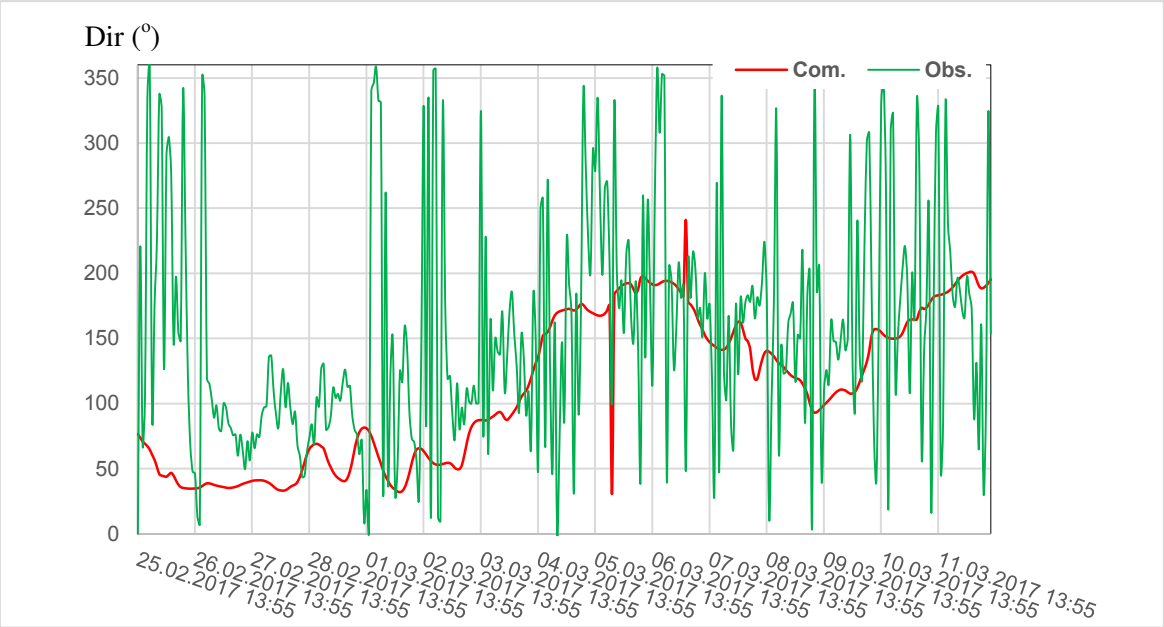


Figure 14. Comparison between computed and observed wave direction Dir(o) at point UMO1 from from 25/2 - 12/3/2017

Table 1. Error index between computed and measured significant wave height

| | Error Index | | | |
|---|---|---|---|---|
| Point | Mean error (ME) | Root mean square error (RMSE) | Standard deviation of error (SD) | Scatter index (SI) |
| Period 1 | | | | |
| GCO1 | 0.055 | 0.235 | 0.228 | 0.558 |
| UMO1 | 0.055 | 0.236 | 0.229 | 0.270 |
| Period 2 | | | | |
| GCO1 | 0.1 | 0.31 | 0.30 | 0.27 |
| UMO1 | 0.01 | 0.11 | 0.11 | 0.34 |

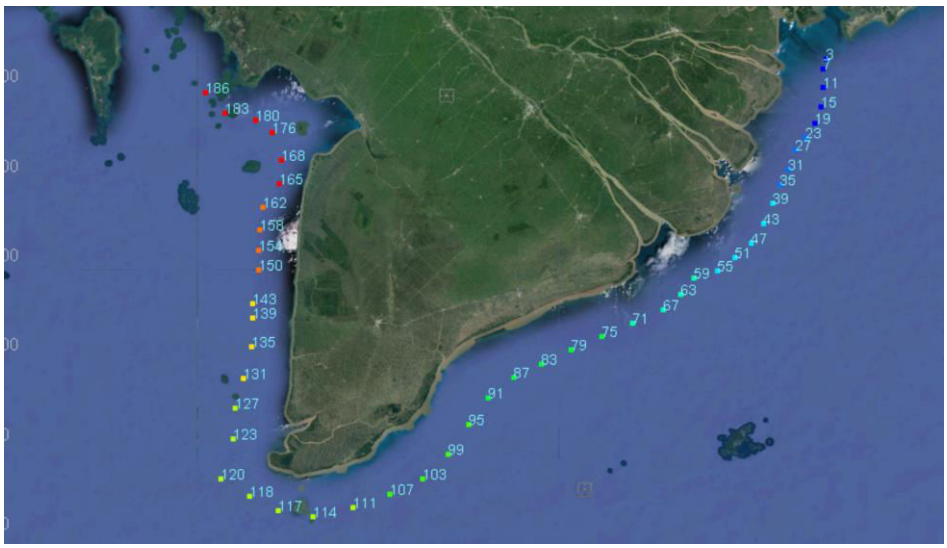

Figure 15. Location of mobile station in Go Cong and U Minh

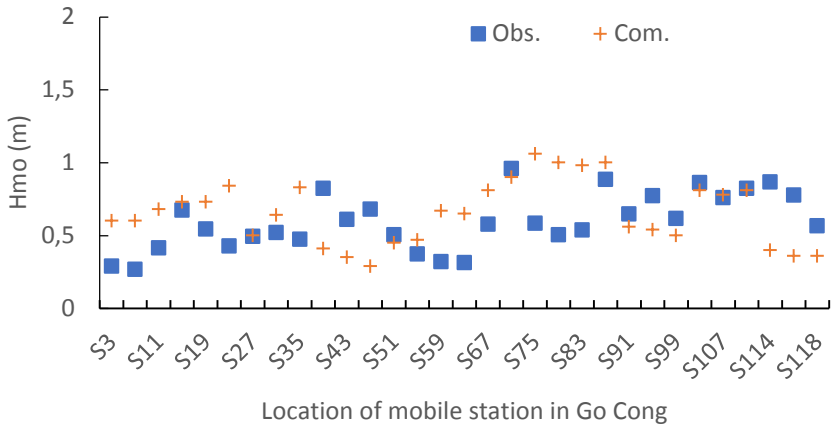


Figure 16. Comparison between observed and computed wave height at the mobile stations in Go Cong

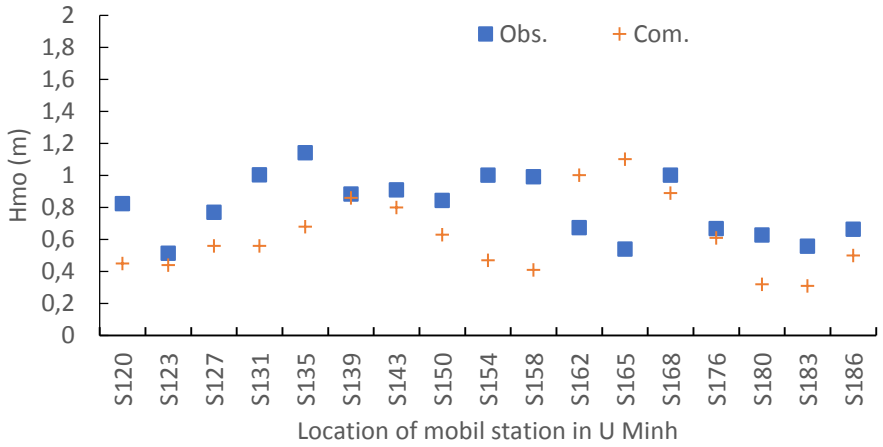


Figure 17. Comparison between observed and computed wave height at the mobile stations in U Minh

### b. Computed results in Go Cong coastal zone

Tomawac wave model was set up to simulate the wave propagation in East Sea, Go Cong coastal area and U Minh coastal area over a period of 8 full years, from Jan. 2009 to Dec. 2016. The results of model include wave height, wave direction and wave period.

**Wave characteristics in Go Cong Coastal zone**

In order to analyze the wave characteristics in Go Cong coastal area, 3 points in Go Cong zone (GC5, GC6, GC7) are considered. The locations of these points are presented in Fig.18. In Go Cong coastal zone, GC5 is located in the northern part and is 1.5 km far from the shoreline, GC6 and GC7 are successively 1.5 km and 2.3 km far from the shoreline.

More specifically, the wave height and wave direction are analyzed by plotting the wave roses at the considered points. There are in total 13 wave roses for each considered point. The first twelve wave roses, corresponding to the 12 separate months of the year in eight consecutive years, are used to analyze the variations of wave direction in every month. The last one, corresponding to the period of 8 consecutive years, is used to analyze the wave direction in 8 consecutive years. These wave roses are presented from Fig.19 to Fig.27

The wave roses in Go Cong coast indicate that there are clearly two wave seasons. From October to March, under the effect of strong wind from the North – East sector, the dominant wave direction is in E and ESE. From April to September, the waves are affected by wind from the South – West sector, the dominant wave direction is in SSE.

The wave roses at GC5 and GC6 show that the wave directions are almost perpendicular to the shoreline in monsoon and almost parallel to the shoreline in summer. Due to the strong winds from the North – East sector, wave heights in monsoon season are clearly higher than the waves in the summer season (Fig.25 and Fig.26).

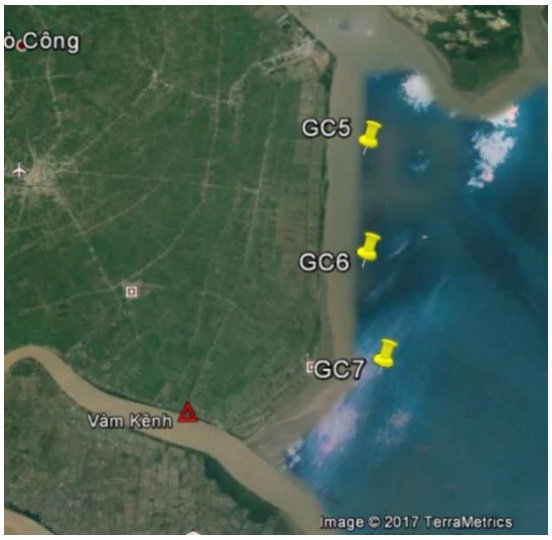


Figure 18. Locations of considered points in Go Cong coastal zone

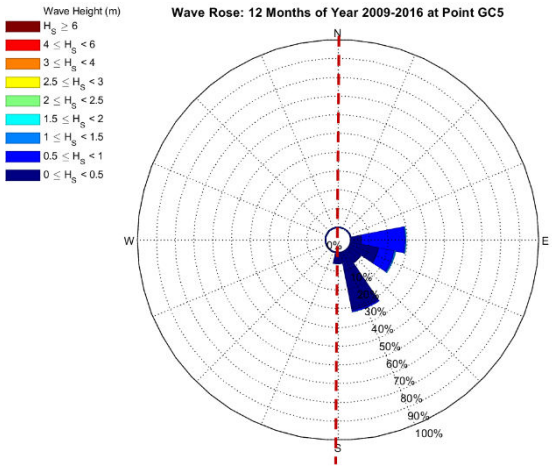


Figure 19. Wave rose at point GC5 over the 8-year period (2009-2016)

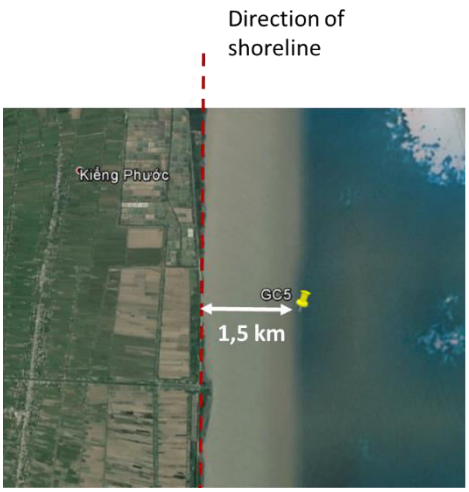


Figure 20. Location of point GC5

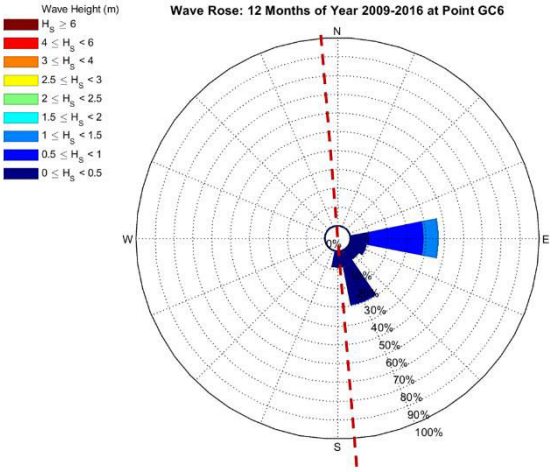


Figure 21. Wave rose at point GC6 over the 8-year period (2009-2016)


Figure 22. Location of point GC6

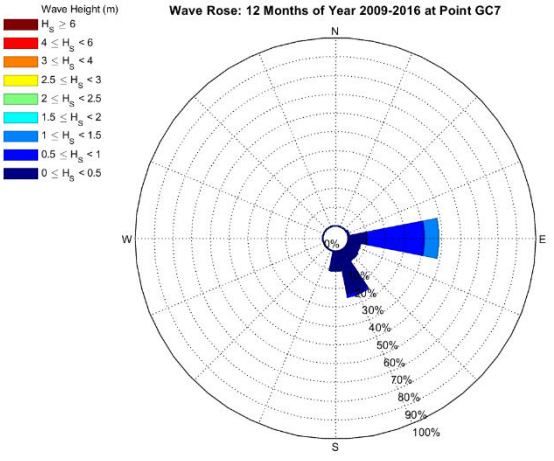


Figure 23. Wave rose at point GC7 over the 8-year period (2009-2016)

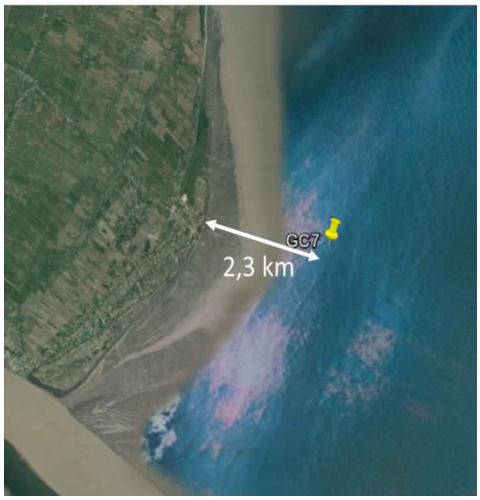


Figure 24. Location of point GC7

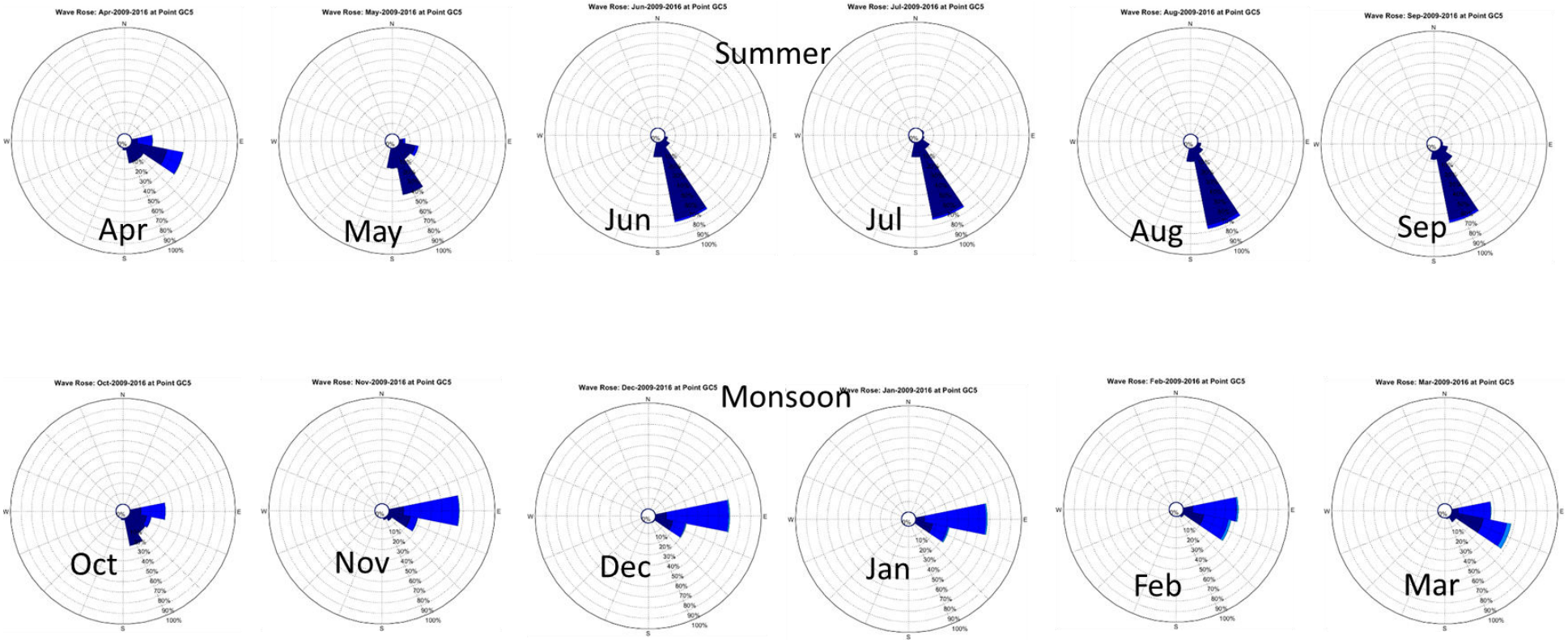


Figure 25. Wave roses for each month of the year (based on the average of the 8 simulated years) at GC5 location.

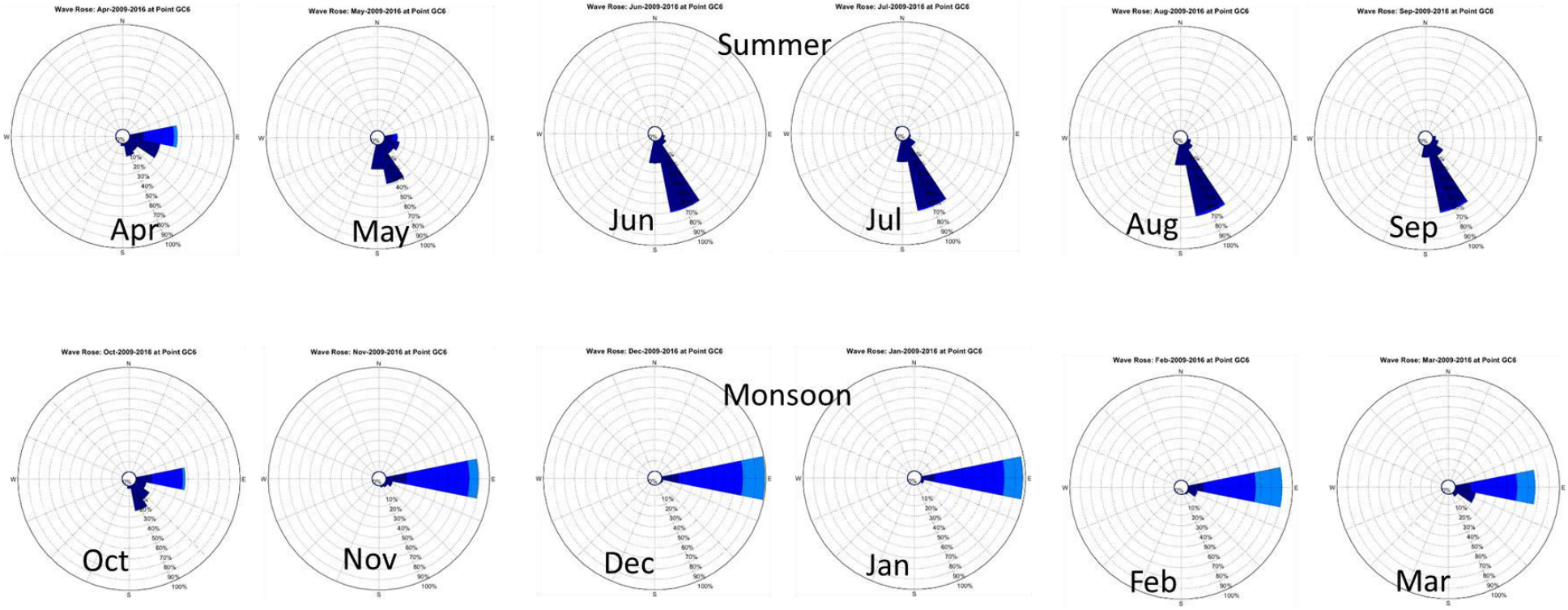


Figure 26. Wave roses for each month of the year (based on the average of the 8 simulated years) at GC6 location.

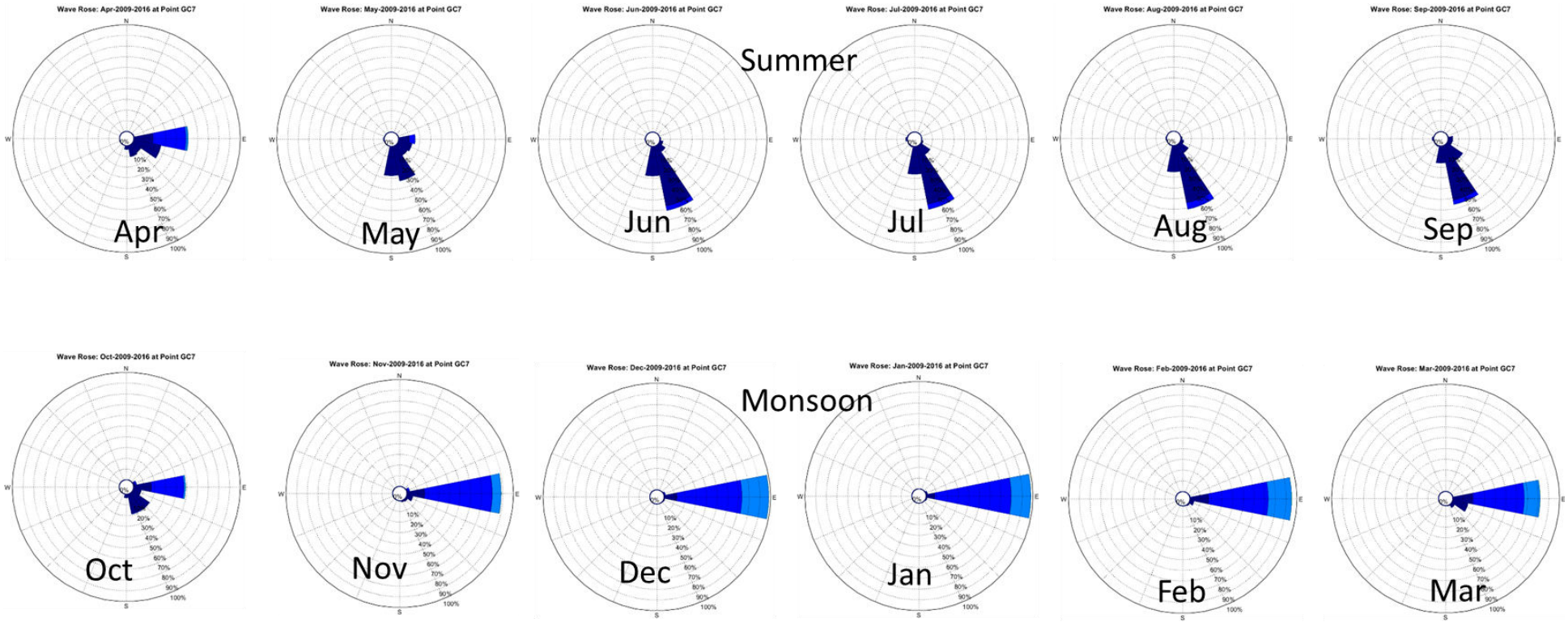


Figure 27. Wave roses for each month of the year (based on the average of the 8 simulated years) at GC7 location.

## Wave statistical analysis

Wave data from the results of wave model are analyzed to find the statistical distributions for the significant wave height, the mean wave direction and the wave period. The probability of wave height, wave direction and wave period occurrence at 3 points along the Go Cong coastline are presented from Fig.28 to Fig 36.

The graph in 3D for the variability of wave height distribution in each year and in each location along the beach are shown in Fig. 37, Fig. 38 and Fig.39.

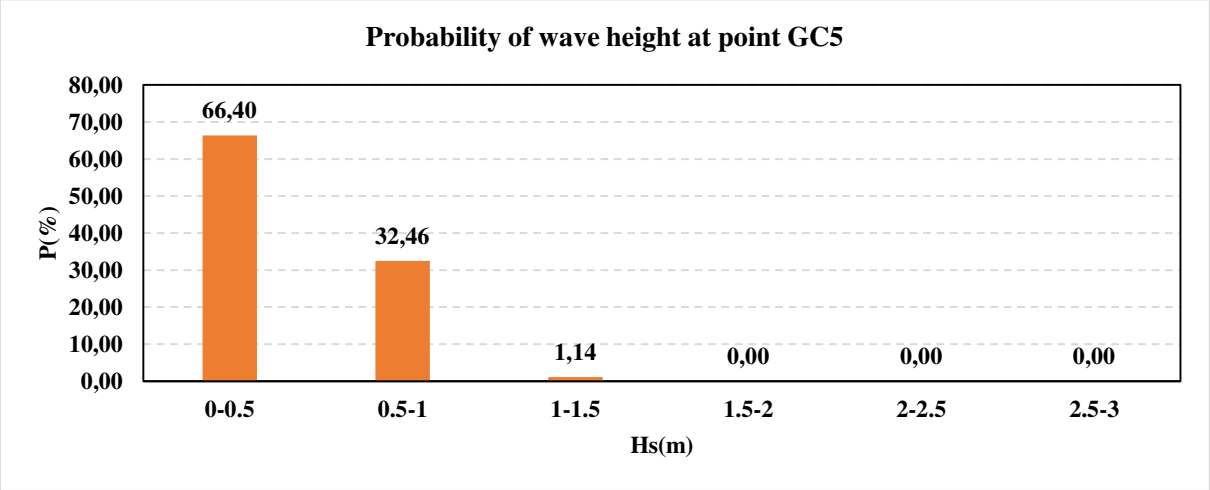


Figure 28. Histogram of significant wave height at point GC5

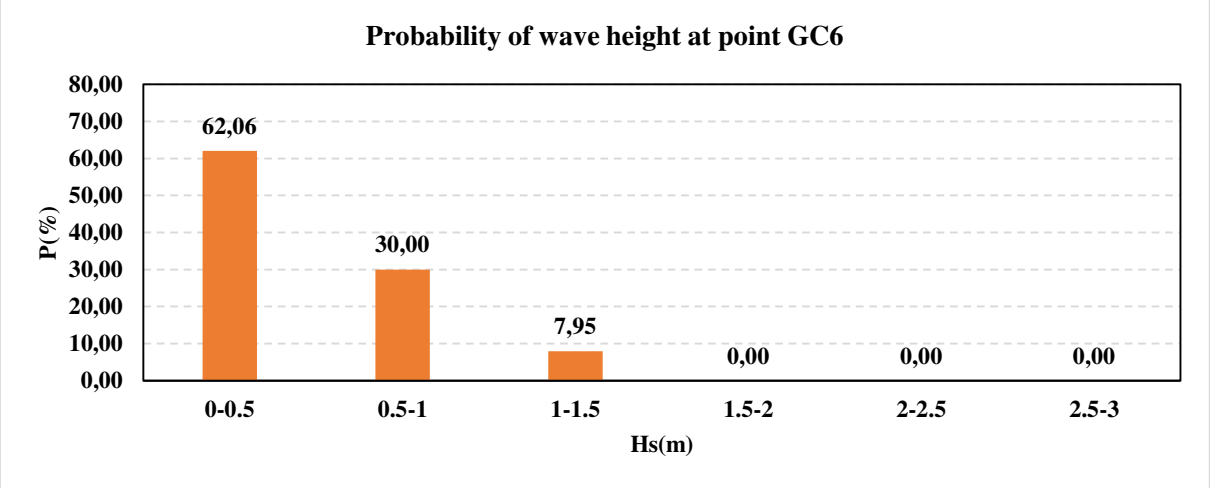


Figure 29. Histogram of significant wave height at point GC6

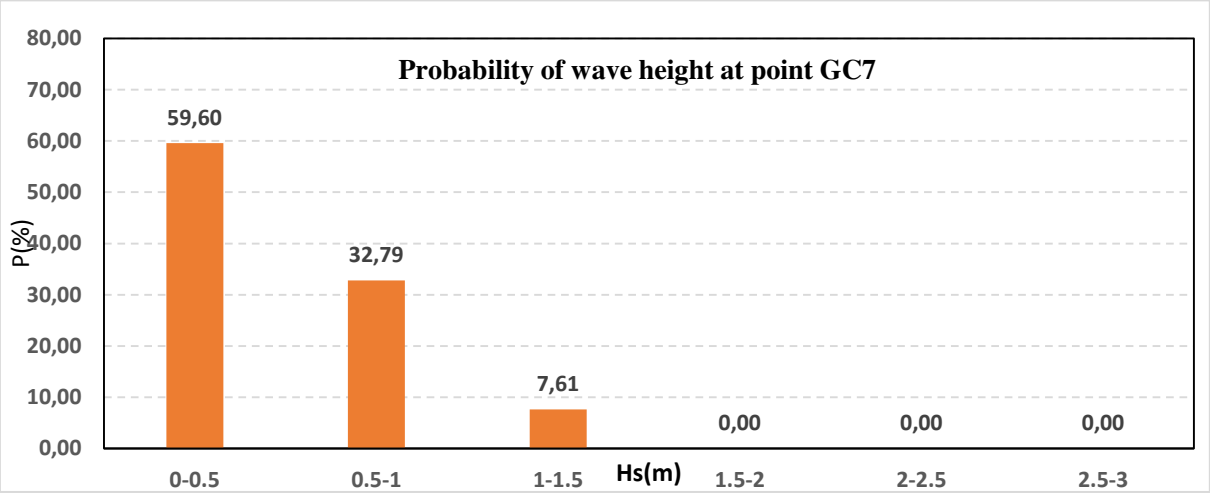


Figure 30. Histogram of significant wave height at point GC7

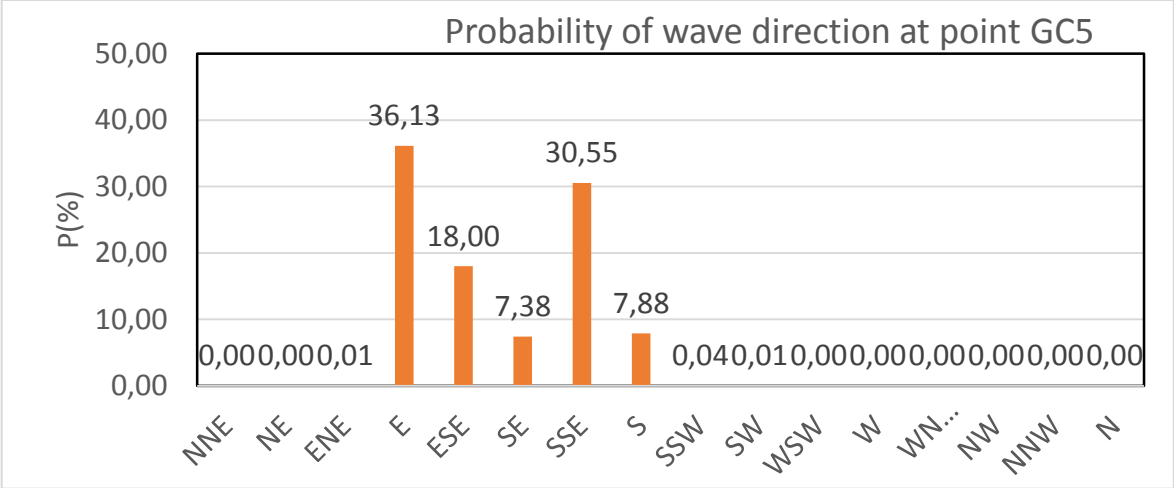


Figure 31. Histogram of mean wave direction at point GC5

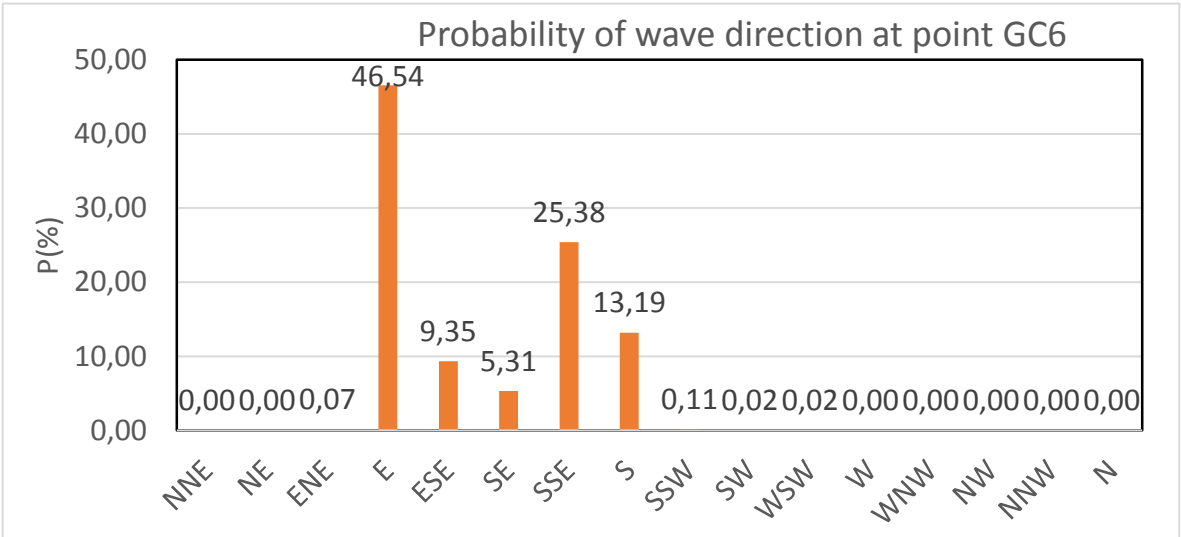


Figure 32. Histogram of mean wave direction at point GC6

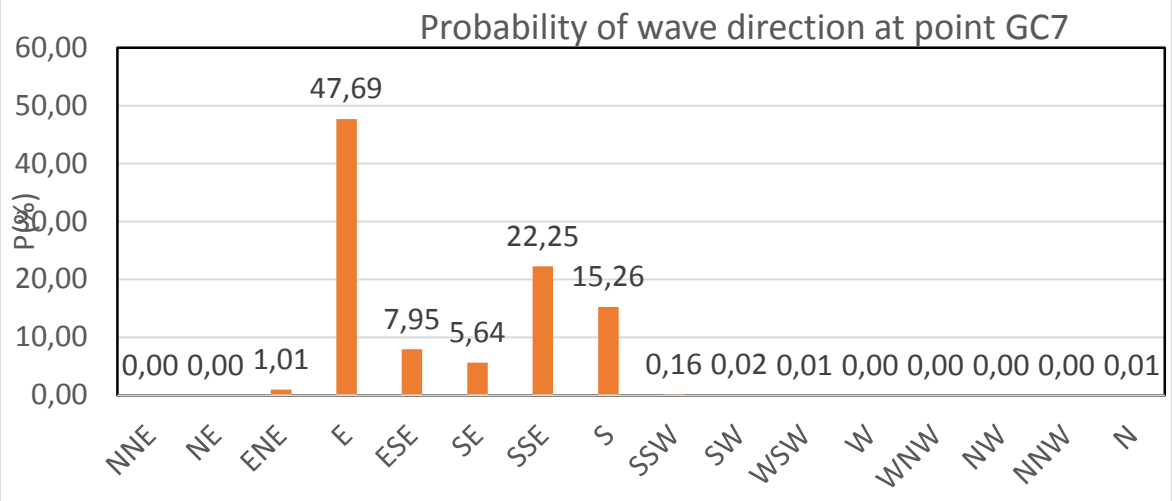


Figure 33. Histogram of mean wave direction at point GC7

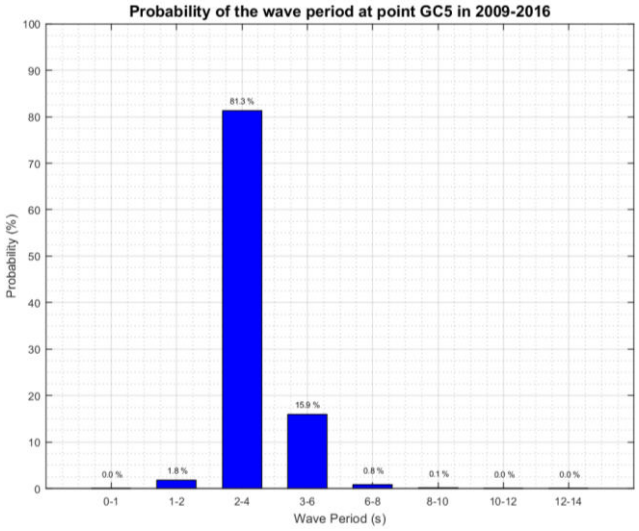


Figure 34. Histogram of wave period at point CG5

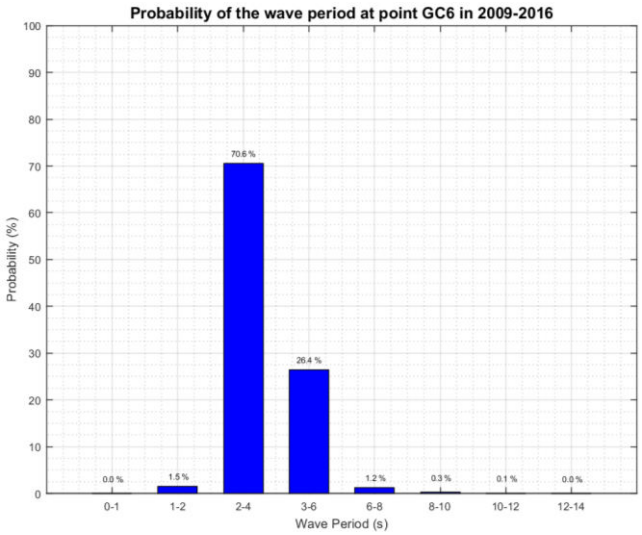


Figure 35. Histogram of wave period at point CG6

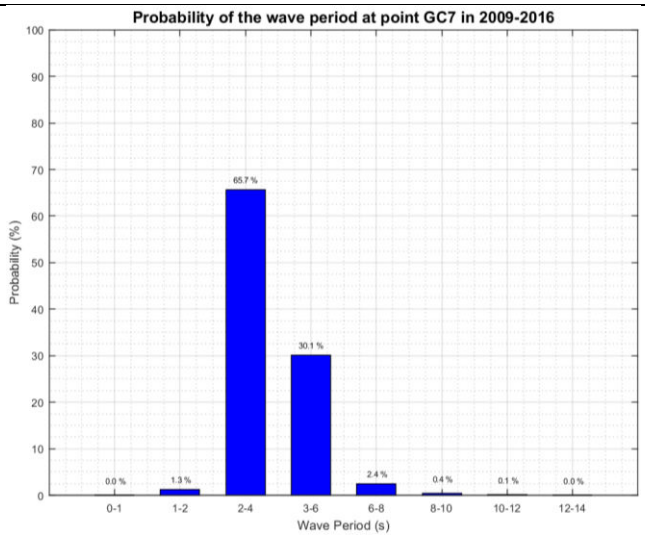


Figure 36. Histogram of wave period at point CG7

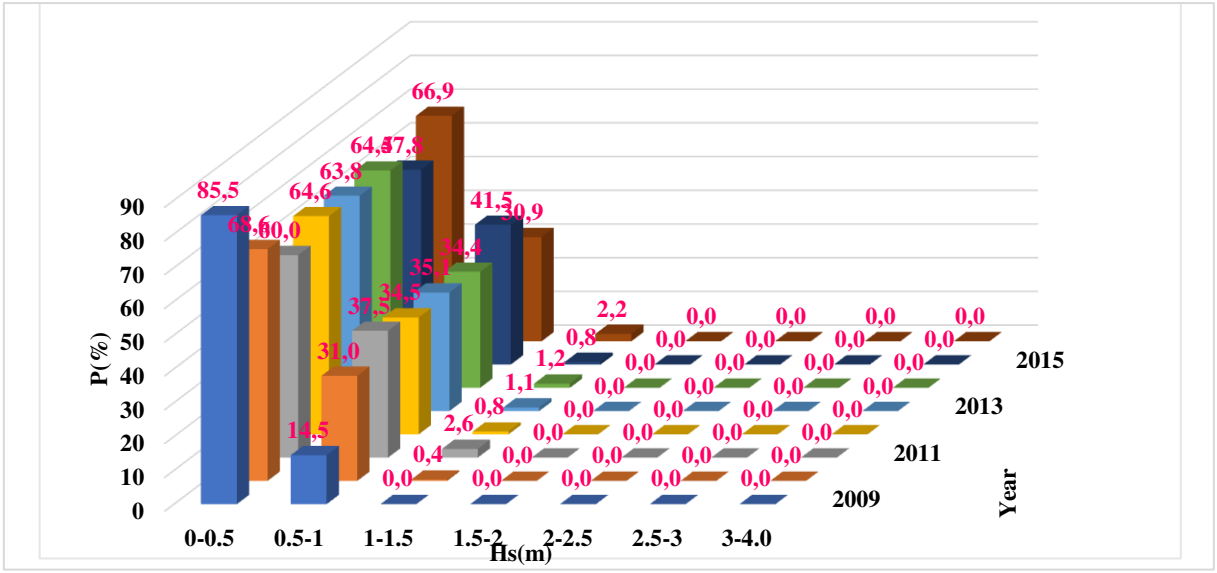


Figure 37. Histogram of significant wave height at point GC5 from 2009 to 2016

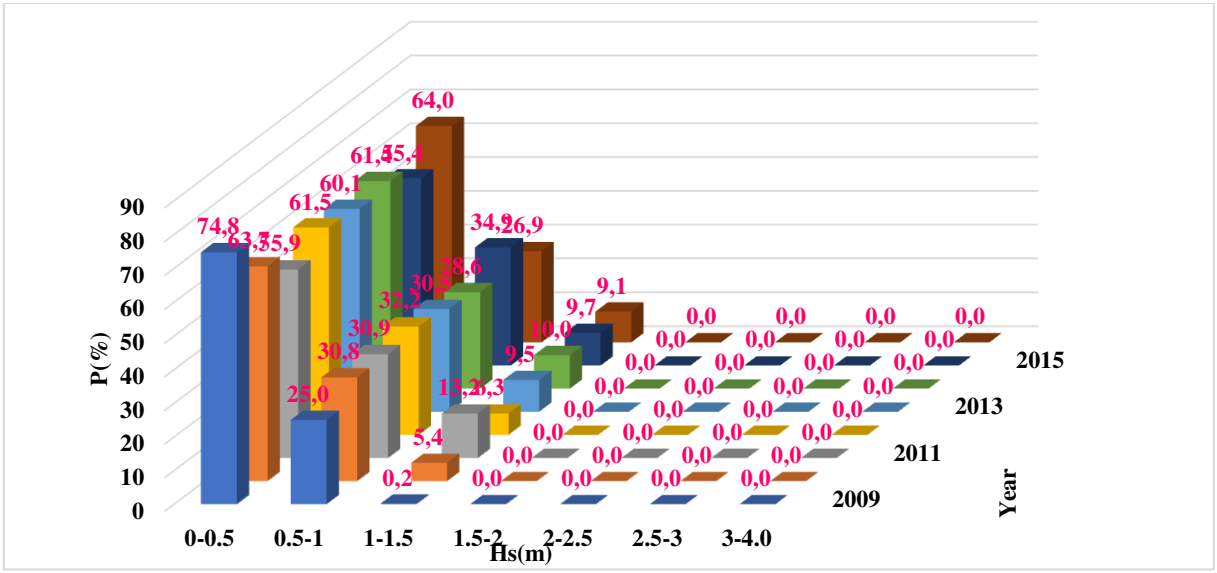


Figure 38. Histogram of wave significant height at GC6 from 2009 to 2016

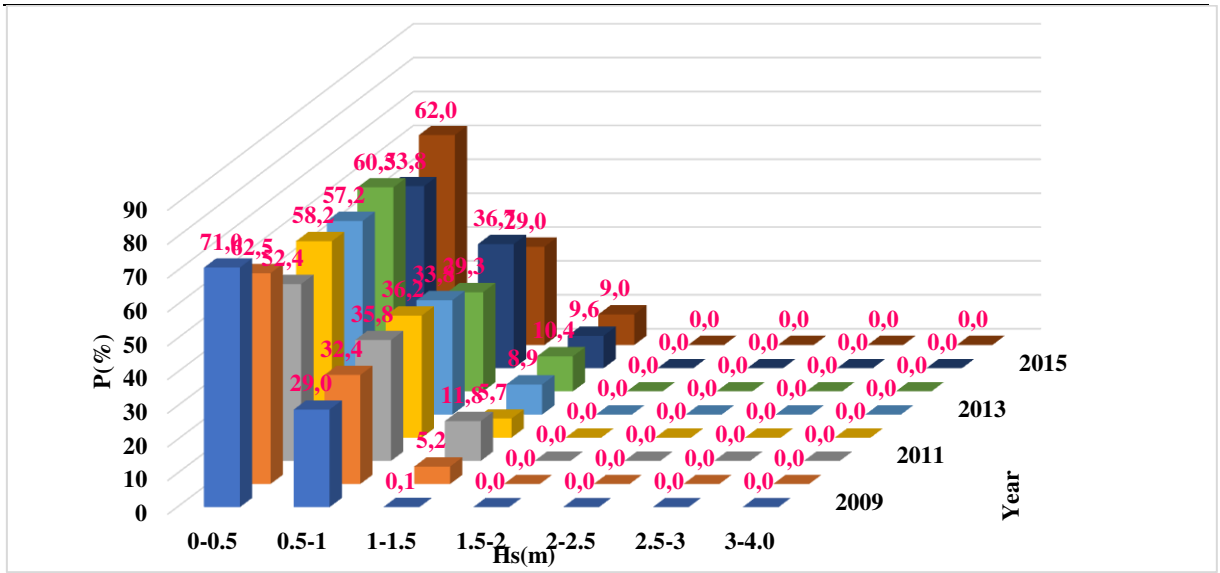


Figure 39. Histogram of wave significant height at point GC7 from 2009 to 2016

Table 2. Wave statistical analysis in Go Cong coastal zone (point GC6)

| | | |
|---|---|---|
| Significant wave height | < 0.5m | P = 62.06% |
| | 0.5m – 1m | P = 30.0% |
| | 1m – 1.5m | P = 7.95% |
| Wave direction | E | P = 46.54% |
| | ESE | P = 9.35% |
| | SES | P = 25.38% |
| | S | P= 13.19% |
| Wave period | 2s – 6s | |

Based on wave statistical analysis, the wave characteristics in Go Cong coastal area present the following features:

- The wave direction over Go Cong area shows a two-regime pattern depending upon the season: summer conditions from April to September and monsoon conditions from October to March.
- In monsoon season, the dominant wave direction is E and ESE, while in summer the dominant wave direction is SES and S. Results on wave direction during the two seasons show that the East direction have occurred approximately 46.5% while the occurrences of SES and S directions are 25.4% and 13.2% respectively. The other wave directions have an occurrence probability lower than 10%.
- The wave heights during two seasons are quite different. High wave conditions occur more frequently in the monsoon season than in the summer season. Sea-states with over 1 meter-height have a probability of 8%, the probability of the wave height less than 0.5m is about 62. %, and it is about 30% for wave heights in range of 0.5m – 1.00m.

### c. Computed results in U Minh coastal zone

The Tomawacave model was set up to simulate the wave propagation in East Sea, Go Cong coastal area and U Minh coasal areat over a period of 8 full years, from Jan. 2009 to Dec. 2016. The results of model include wave height, wave direction and wave period.

**Wave characteristics in U Minh Coastal zone**

In order to analyze the wave characteristics at the study areas, 3 points in U Minh coastal area (UM, UM6, UM7) are considered. The locations of these points are presented in Figure 27. In U Minh coastal zone, UM5 is located in the northern part and is 2.3km far from the shoreline, UM6 and UM7 are respectively 2.18km and 1.95km far from the shoreline.

Also, the significant wave height and mean wave direction are analyzed by plotting the wave roses at the considered points. There are in total 13 wave roses for each considered point. The twelve wave roses, corresponding to 12 separate months of the year in eight consecutive years, are used to analyze the variations of wave direction in every month. The rest one corresponding to the period of 8 consecutive years is used to analyze the wave direction in 8 consecutive years. These wave roses are presented from Figure 28 to Figure 36.


Figure 40. Locations of considered points in U Minh Coastal zone

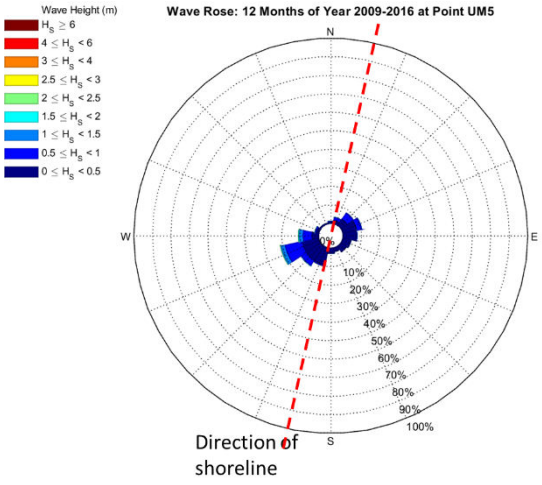


Figure 41. Wave rose at point UM5 over the 8-year period (2009-2016)

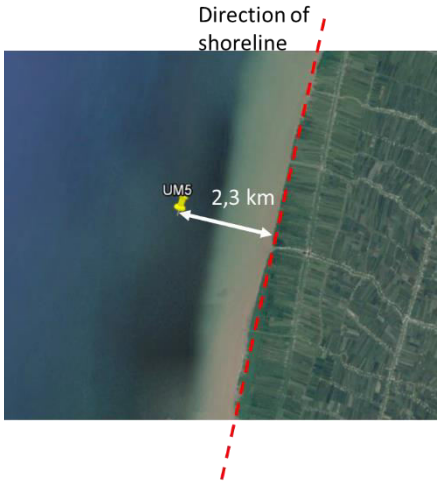


Figure 42. Location of point UM5

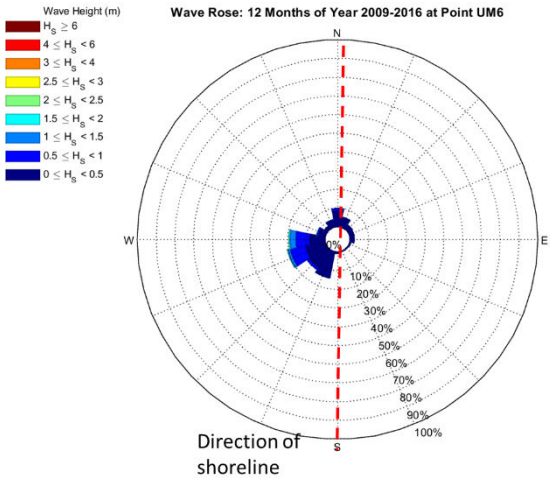


Figure 43. Wave rose at point UM6 over the 8-year period (2009-2016)

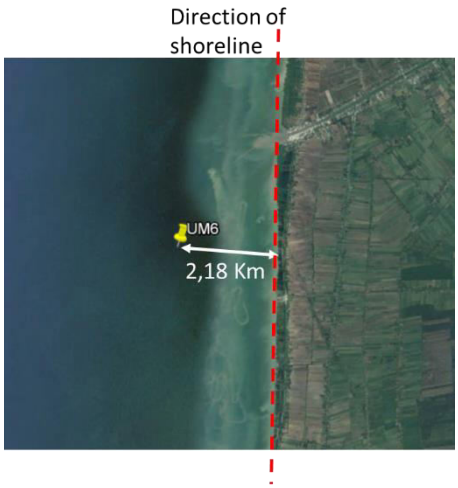


Figure 44. Location of point UM6

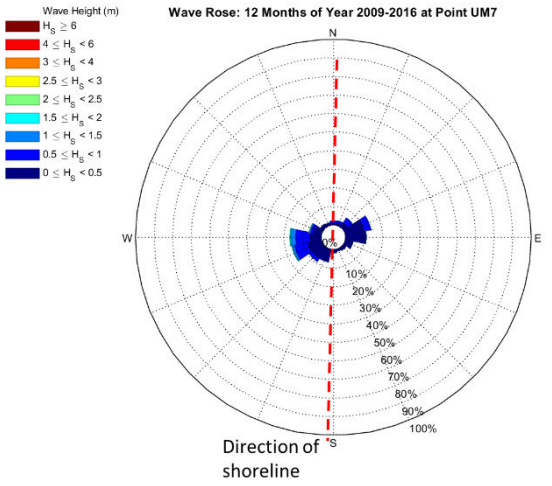


Figure 45. Wave rose at point UM7 over the 8-year period (2009-2016)

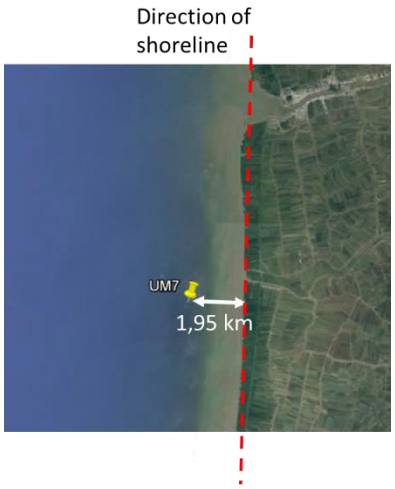


Figure 46. Location of point UM7

The wave roses in U Minh coast indicate that the wave direction is very complicated in U Minh compared to Go Cong area. From October to March, under the effect of wind from the North – East sector, the dominant wave direction is in E, NE, and ENE depending on the location of the considered points. From April to September, the waves are affected by wind from the South – West sector, the dominant wave direction is from W to WSW.

The wave roses at the considered points show that the wave directions are perpendicular to the shoreline during the summer season and almost parallel to the shoreline during monsoon season (it's vice versa in Go Cong). The wave height in summer season is also higher than in monsoon season (Figure 34, Figure 35, and Figure 36). This is related to the effective fetch for the generation of waves, which is clearly shorter for the winds from the South – West sector of the monsoon season, due to the local shape of the coastline.

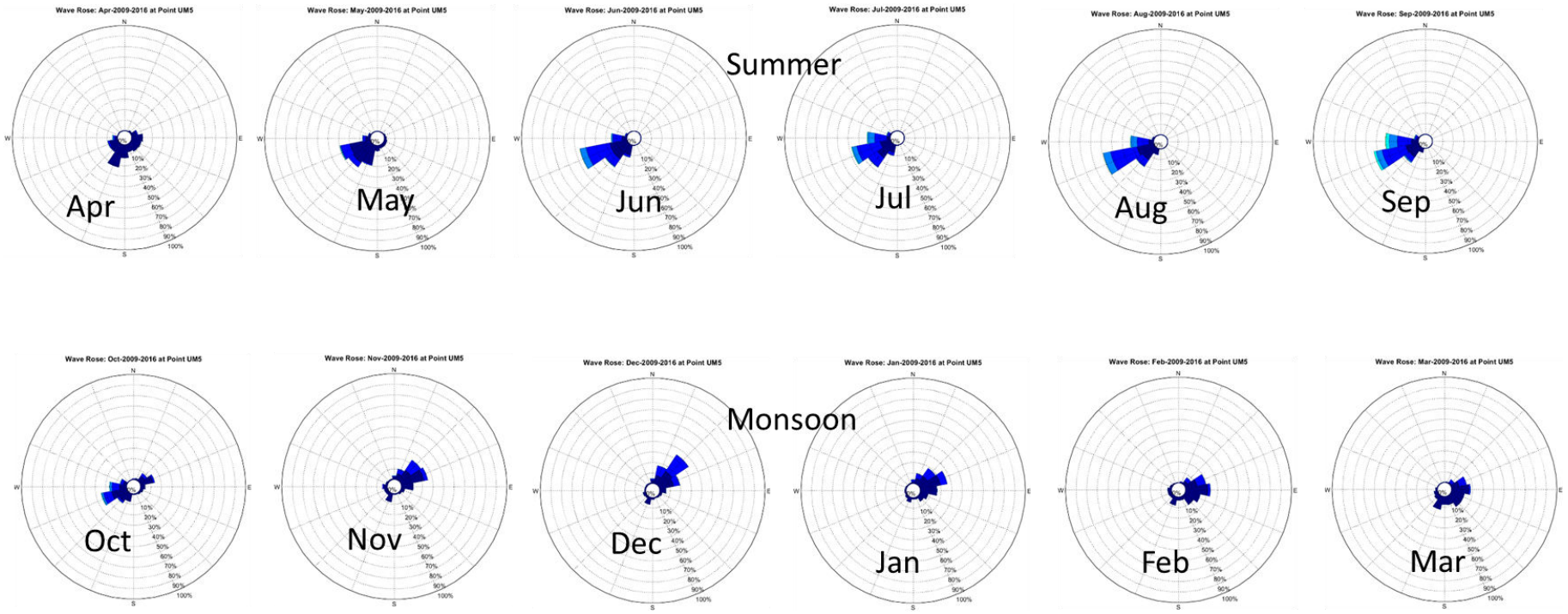


Figure 47. Wave roses for each month of the year (based on the average of the 8 simulated years) at UM5 location.

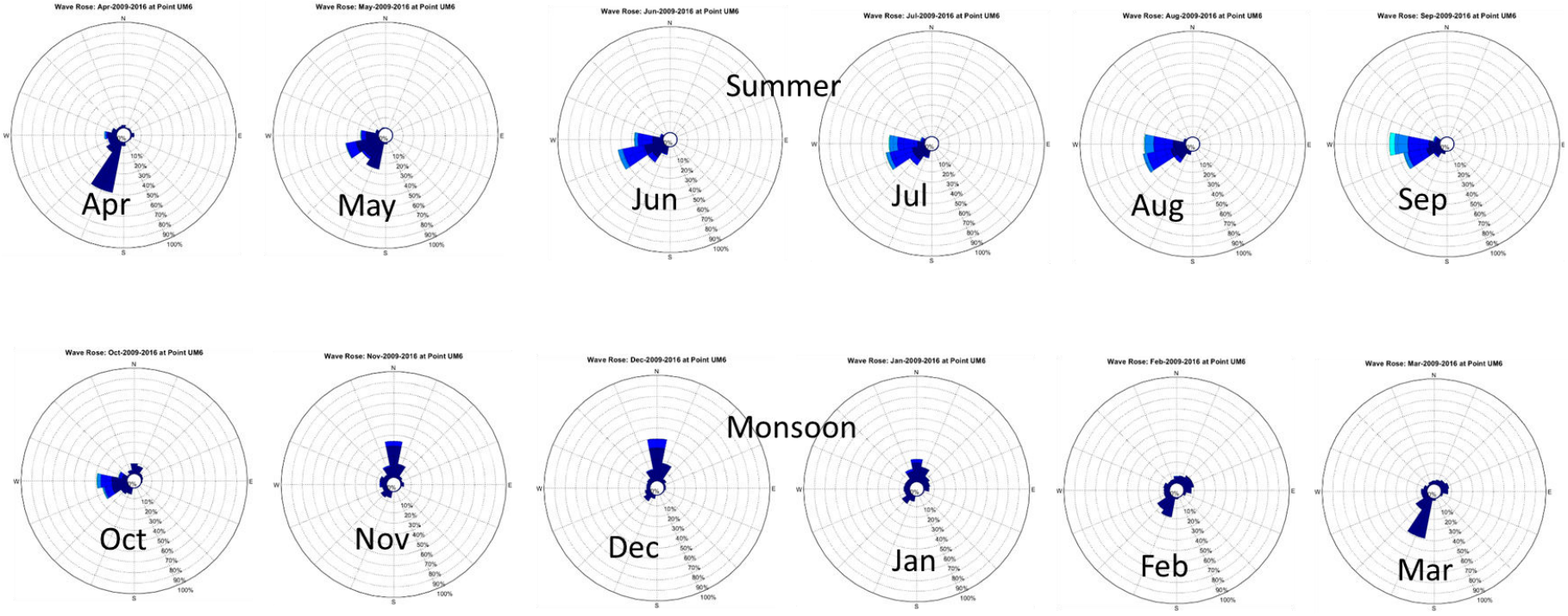


Figure 48. Wave roses for each month of the year (based on the average of the 8 simulated years) at UM6 location.

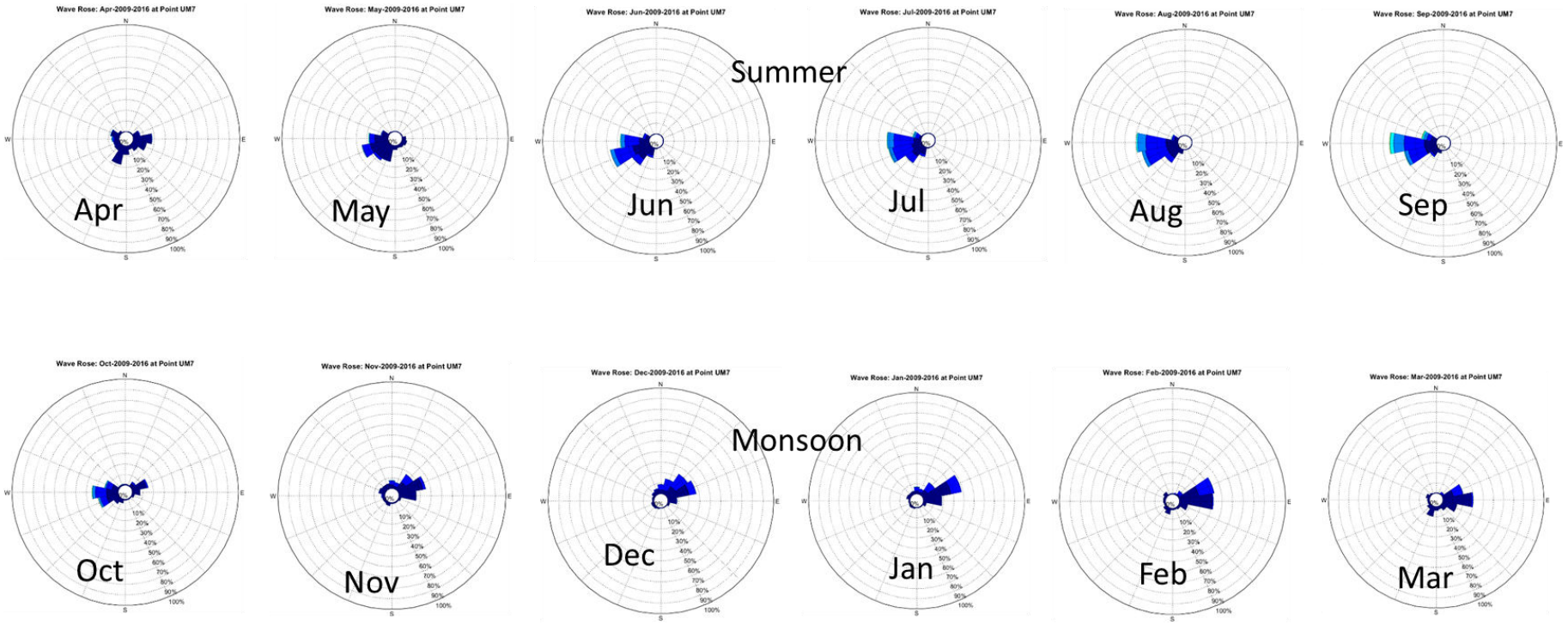


Figure 49. Wave roses for each month of the year (based on the average of the 8 simulated years) at UM7 location.

## Wave statistical analysis

Wave data from the results of wave model are analyzed to find the statistical distributions for the significant wave height, mean wave direction and the wave period. The probability of wave height, wave direction and wave period occurrence at 3 points along the U Minh coastline are presented from Figure 37 to Figure 45.

The graph in 3D for the variability of wave height probability in each year and in each location along the beach are shown in Figure 46, Figure 47, and Figure 48.

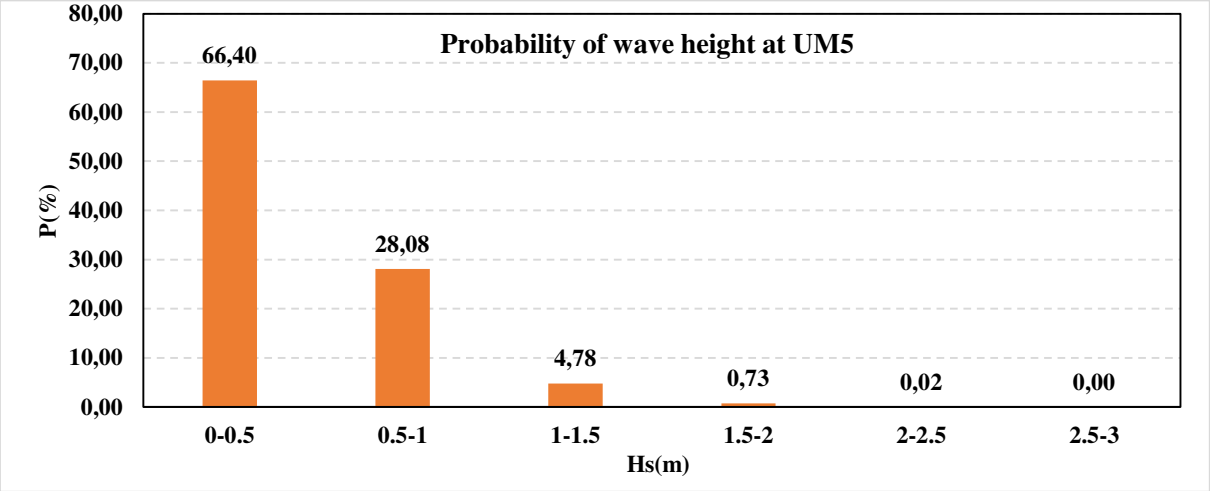


Figure 50. Histogram of significant wave height at point UM5.

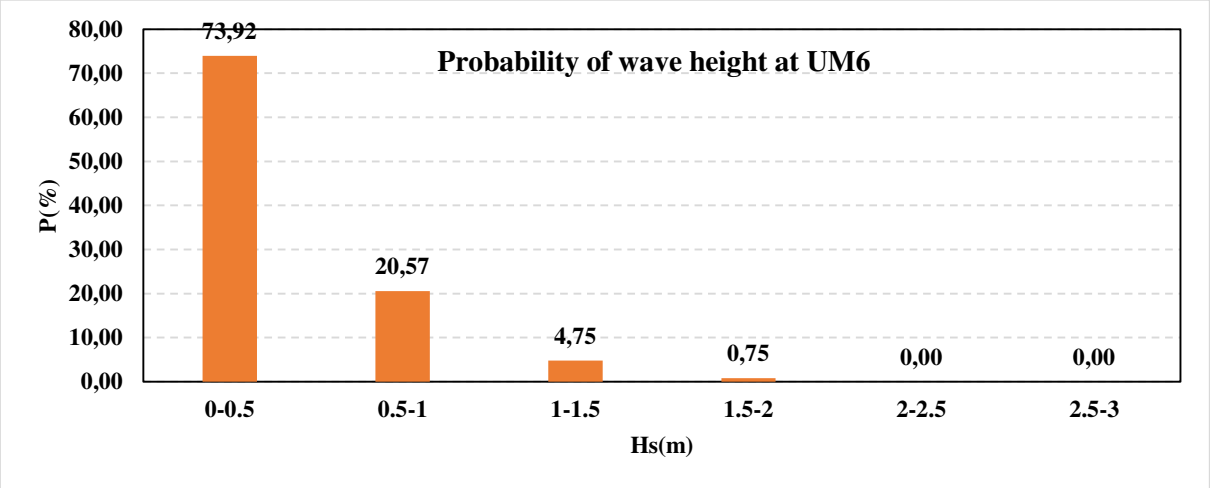


Figure 51. Histogram of significant wave height at point UM6.

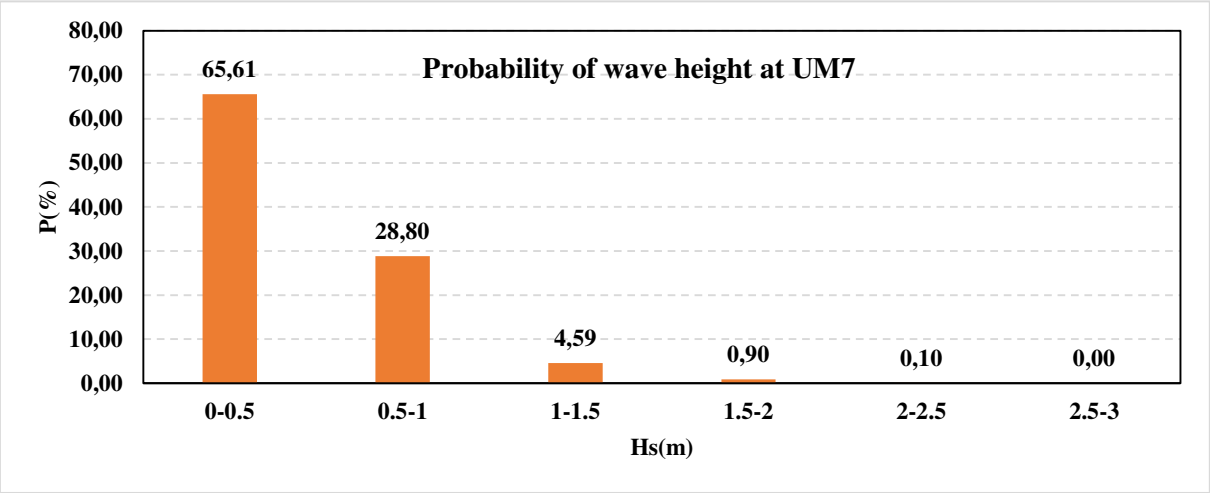


Figure 52. Histogram of significant wave height at point UM7.

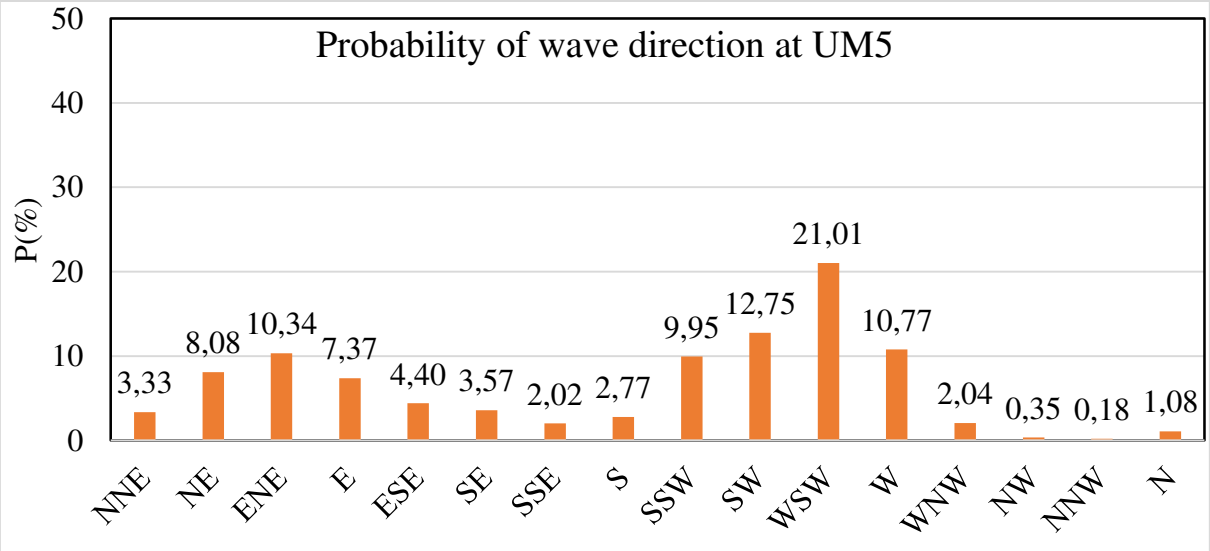


Figure 53. Histogram of mean wave direction at point UM5.

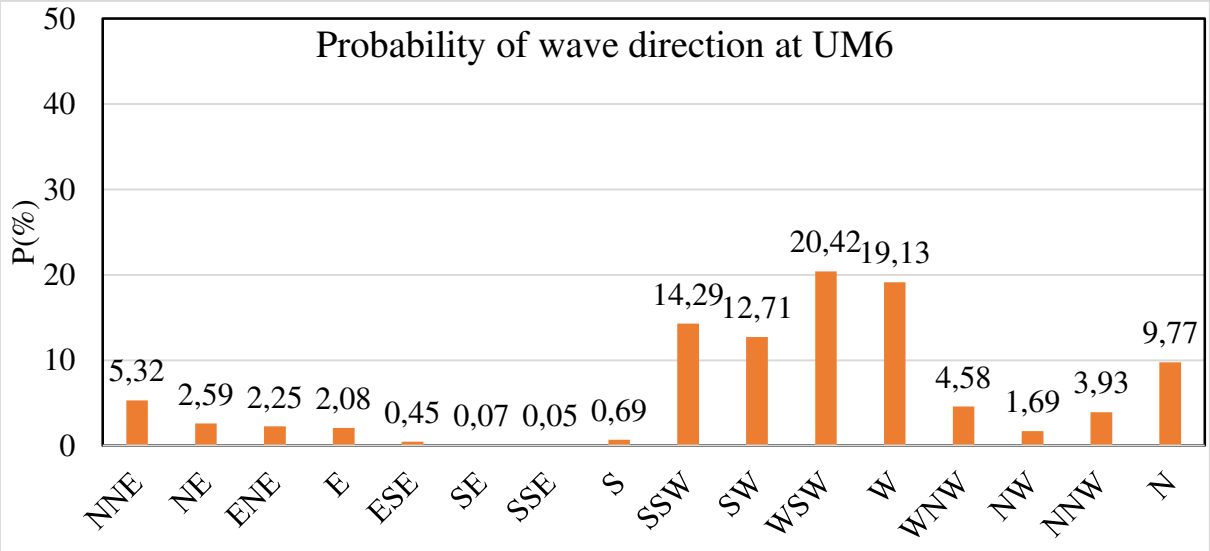


Figure 54. Histogram of mean wave direction at point UM6.

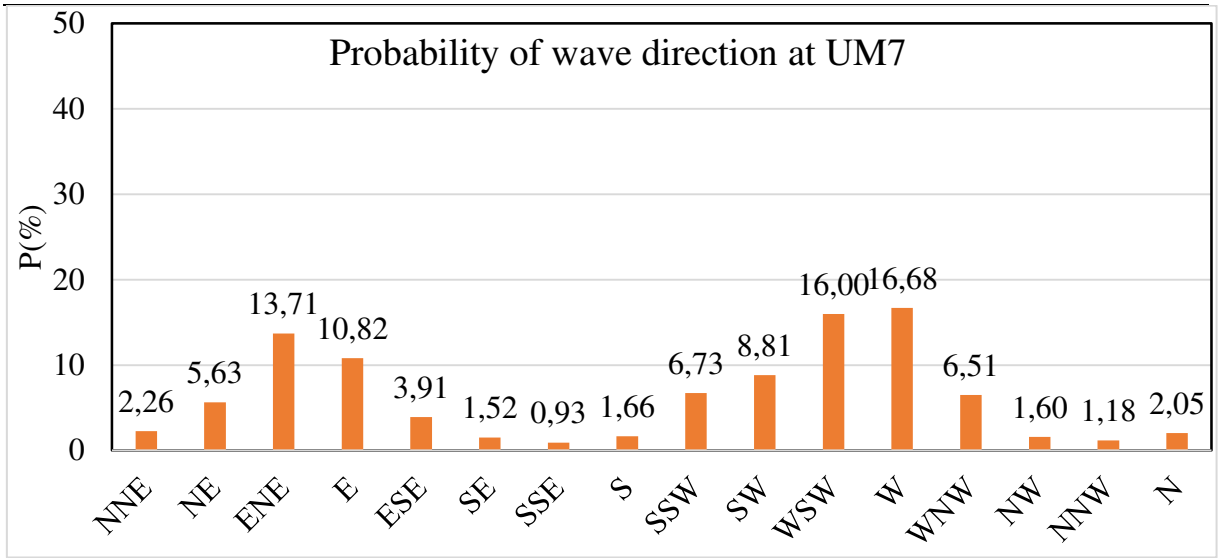


Figure 55. Histogram of mean wave direction at point UM7.

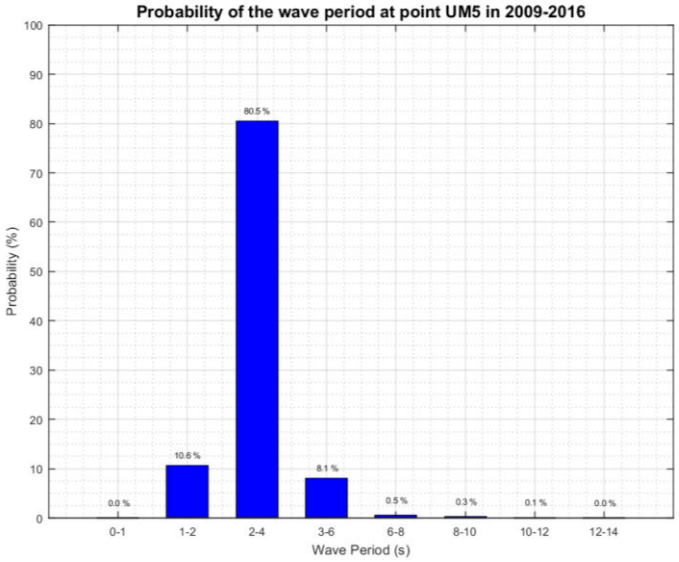


Figure 56. Histogram of wave period at point UM5.

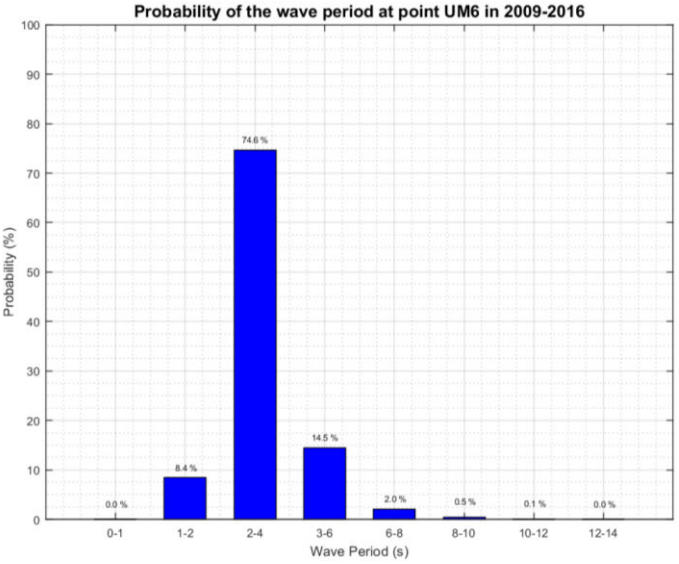


Figure 57. Histogram of wave period at point UM6.

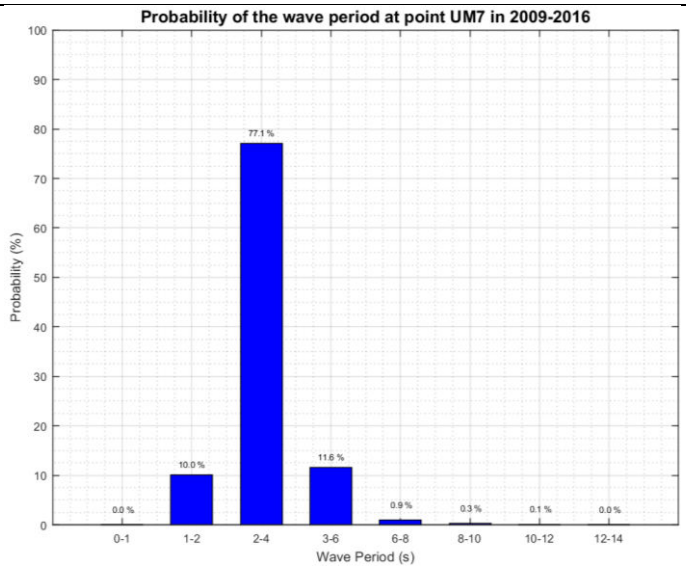


Figure 58. Histogram of wave period at point UM7.

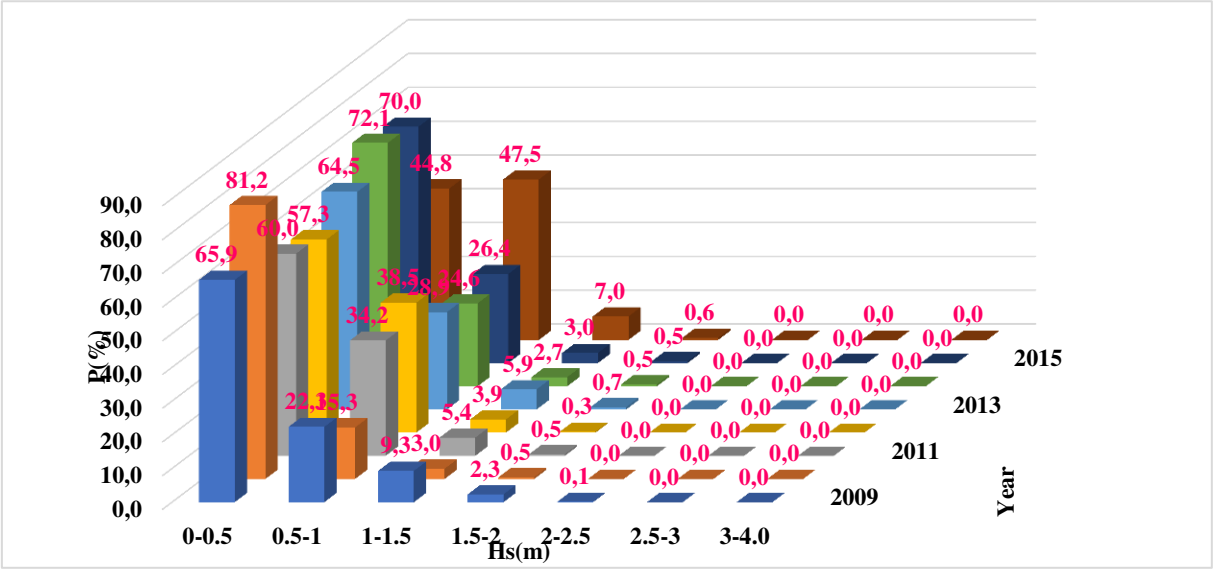


Figure 59. Histogram of significant wave height at point UM5 from 2009 to 2016

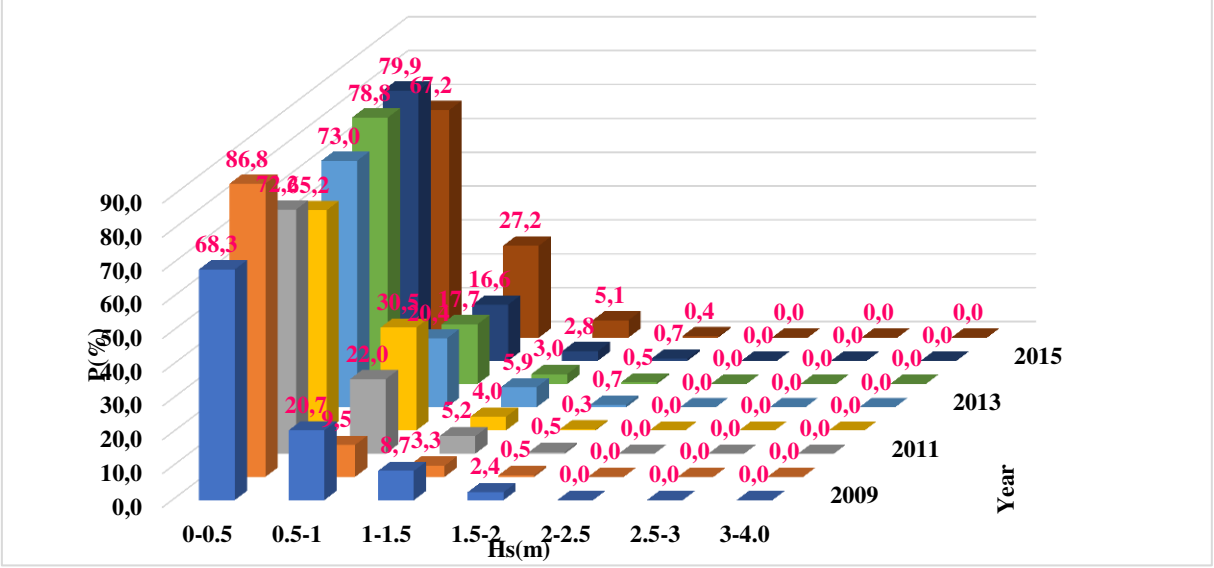


Figure 60. Histogram of significant wave height at point UM6 from 2009 to 2016

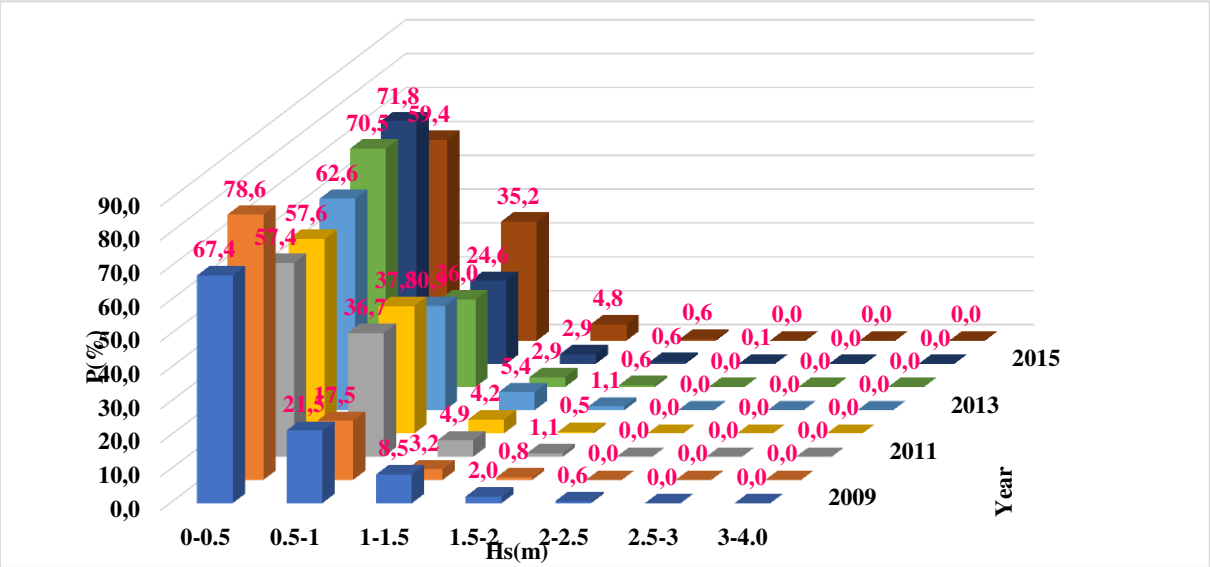


Figure 61. Histogram of significant wave height at point UM7 from 2009 to 2016

Table 3. Wave statistical analysis in U Minh coastal zone (point UM5)

| | | |
|---|---|---|
| Significant wave height | < 0.5m | P = 73.92% |
| | 0.5m – 1m | P = 28.08% |
| | 1m – 1.5m | P = 4.78% |
| | 1.5 m – 2 m | P = 0.73% |
| Wave direction | NE-ENE-E | P = 25.79% |
| | W-WSW-SW-SWS_ | P = 54.48% |
| Wave period | 2s-4s | P = 80.50% |

Based on wave statistical analysis, the wave characteristics in U Minh coastal area present the following features:

- The wave direction at U Minh shows a two-regime pattern depending upon the season: summer conditions from April to September and monsoon conditions from October to March.
- In monsoon season, the dominant wave direction varies between E, NE and ENE while in summer season the dominant wave direction is from W to SSW. Results on wave direction during the two seasons show that the directions E, NE and ENE occur approximately 25.8% while the occurrences of directions from W to SWS is about 54.6%. The other wave directions have an occurrence probability lower than 5%.
- The wave heights during the two seasons are quite different,. The high wave conditions occur more frequently in the summer season than in the monsoon season. Sea-states with over 1 meter-height have a probability of 4.8%, the probability of the wave height less than 0.5m is about 73.9%, and it is about 28.1% for wave heights in the range 0.5 - 1m.
- The dominant wave period is in the range 2s – 4s, without occurrence probability of 80.5%