ASSESSMENT OF PERFORMANCE OF INTERPOLATION METHODS FOR TEMPORAL RESOLUTION OF WIND DATA ON WAVE MODELLING

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ABSTRACT

ASSESSMENT OF PERFORMANCE OF INTERPOLATION METHODS FOR TEMPORAL RESOLUTION OF WIND DATA ON WAVE MODELLING

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In this thesis, the performance of different interpolation techniques for wind hindcasting have been assessed and a computer model based study have been performed on its effects on wave hindcasting. Climate Forecast System Reanalysis (CFSR) dataset between 1979 and 2010 is used for long term time series analysis and extreme event analysis in Black Sea region. The aims are to obtain new dataset using the existing dataset, to determine the reliability of statistical analysis of winds and to evaluate the error margins in numeric wave models. W61, a parametric wave hindcasting model has been used for long term and extreme wave analysis and WAVEWATCH III has been used for further analysis of 3 extreme events within the Black Sea. Several statistical parameters are used to evaluate and compare the interpolation methods including Mean Absolute Error, Coefficient of Variation Root Mean Square Error and Normalized Bias.

The wave and statistical analysis results indicated that the performances of the interpolation methods for wave analysis are not compatible with the wind analysis results. Also, performances of the interpolation methods varies through the analyzed 25 points within the Black Sea for both long term and extreme wave analysis.

Keywords: Black Sea, Wave models, Data Interpolation, Wave Statistics, Wind datasets

ÖZ

FARKLI ZAMAN ÇÖZÜNÜRLÜĞÜNE SAHİP RÜZGAR VERİ SETLERİNİN DALGA TAHMİN MODELLEMESİNDE PERFORMANS DEĞERLENDİRMESİ

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Bu tezde, rüzgâr veri tahmini amacıyla kullanılan farklı interpolasyon metodlarının performansı değerlendirilmiş ve bilgisayar modeli kullanılarak; bu farklı metodlarla elde edilen veri setlerinin dalga tahminleri üzerindeki etkisi incelenmiştir. Karadeniz bölgesi için yapılan bu çalışmalarda 1979 ile 2010 yılları arası için var olan CFSR veri setleri kullanılmıştır. Bu tezdeki amaç; eldeki veri setleri kullanılarak yeni veri setleri elde etmek, rüzgâr verileri için istatistiksel veri atama yöntemlerin güvenilirliği kontrol etmek, dalga verileri için oluşan hata payları hesaplamaktır. Uzun vadeli dalga analizi ve maksimum dalga istatistiği analizi için W61 dalga tahmin modellemesi ve 3 ekstrem durumun incelenmesi için ise WAVEWATCH III dalga tahmin modellemesi kullanılmıştır. İnterpolasyon modellerinin değerlendirilmesi ve karşılaştırılması için Ortalama Mutlak Hata, Ortalama Hata Kareleri Karekökü ve Düzgelenmiş Sapma gibi istatistik parametreleri kullanılmıştır.

İstatistik analizi sonuçlarında, rüzgar ve dalga analizlerinin farklı interpolasyon metodları için farklılık gösterdiği görülmüştür. Ek olarak, Karadeniz bölgesinde incelenen 25 nokta için farklı interpolasyon metodlarının performanslarının değişkenlik gösterdiği gözlemlenmiştir.

Anahtar Kelimeler: Karadeniz, Dalga Modelleri, Veri Interpolasyonu, Dalga İstatistiği, Rüzgar Verisetleri

To my family

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CHAPTER 1

INTRODUCTION

One of the main principles of the design of engineering structures is the optimization of safety and economy. It is not practical or economical to design and construct every structure to withstand the most extreme cases. Throughout years as engineering has advanced, each country has established standards and regulations in order to control this optimization. Different structures have been classified according to their importance to the society not just for regular conditions but also for extreme event conditions. During the design procedure of any structure, design engineers have to follow these regulations and assess the risk factors correctly for the design. In order to accomplish this, all forces that the structure will be subjected to through its determined life span has to be estimated correctly.

Structural design loads specified in the codes are: dead loads, live loads, highway bridge loads, railway bridge loads, impact loads, wind loads, wave loads, snow loads and earthquake loads. Also, many other possible additional loads are considered in design stages such as the effect of blast and temperature changes. Loads such as dead loads and live loads can be estimated accurately through measurements and available models but estimation of the environmental forces such as wind loads or earthquake loads are more strained.

Environmental loads are always present and acting on the structures even during the construction phases. The strength of these location-based forces varies through time within the life span of the structures. In-situ data collection through actual measurements would have been the most reliable method for estimation of environmental forces but in order to forecast the future variations in these loads;

knowledge of data throughout decades is needed. Since this is not possible, many forecasting models have been developed for estimation of the environmental loads.

Forecasting models rely on scientific predictions but since they are based on limited amount of actual measurements, these models still possess certain amount of error. Codes and regulations use multiplication factors and coefficients to minimize this error. Still, design engineers have to know the order of the magnitude of such possible errors.

Similar principles apply to coastal engineering. For the design of coastal structures, the main parameters that define the forces the structures will be subjected to, generally, depend on the wave climate. There are many types of waves that have to be considered during the design stage; from short period waves such as wind and swell waves, to long period waves such as tsunamis and tidal waves. This research will be focused on the wind waves.

Generation of the wind waves depend on five variables. These are; wind velocity, fetch distance, storm duration, water depth and fetch width (Ergin, 2011). These parameters, especially the wind climate, is essential for determining the basic wave parameters (wave height and wave period) in addition to determining the dominant wave directions. Since the accuracy of wind input data on the wave analysis is very important, several research have been focused on the reliability of the wind data.

Over the last decade, as coastal engineering has progressed, several wind data collection systems have been developed with different temporal and spatial resolutions. The generated wind datasets and the available measurements such as the meteorological data are used as inputs for wave generation models. Each wave generation model uses different calibration datasets in order to obtain the most accurate results. Even after the calibrations, many of the generated datasets possess some degree of error. Since forecasting mainly depends on predicting future data based on historical observations or hindcasting studies, a certain degree of uncertainty has to be considered and expected. In order to minimize the degree of uncertainty, input data with higher spatial and temporal resolutions are usually preferred. For instance, many of the wave generation models use hourly wind data as input.

For some locations, input wind data with higher resolutions may not be available. For these cases, one of the most common solution is using different interpolation methods to increase the resolutions of the available wind datasets. Similarly, interpolation methods are widely used to generate time series data for data gaps that exist within an existing dataset. Moreover, wave generation models have built-in interpolation methods to be used for numerical computation in higher resolutions and one might have made a selection from a variety of methods available to the user. However, each interpolation method, depending on the mathematical approach it uses, produces different time series data for the same original dataset. Therefore, the selection of the interpolation method has an influence on the degree of the uncertainty of the results of wave generation model.

The differences between the results of different interpolation methods have been discussed and investigated by many researchers for a variety of parameters in climate studies. Many research on the effects of temporal and spatial resolutions of wind data as input for different regions for coastal engineering applications have also been presented in the literature. These studies used original datasets of different resolution and discussed the effect on the results of model applications. Güler et al. (2016a, 2016b) have drawn attention that research on the effects of using different interpolation methods for increasing the temporal resolution of the available wind datasets is limited. They evaluated the performances of many interpolation methods to generate hourly wind speed data for the Black Sea region and tried to determine if any of the interpolation methods is more preferable for increasing the temporal resolution of wind speed data. Considering that wind speed data is one of the main parameters controlling the wind wave generation, the reflecting effects of interpolated wind speed datasets on wave generation in the Black Sea was presented as a further research recommendation. Moreover, the effects of interpolated datasets, as well as the selection of interpolation method to be used as input to wave generation models, has not been discussed in the literature to the best of knowledge of the researchers.

Therefore, the objectives of this study are determined as:

- To determine the effect of using wind data generated by different interpolation methods in wave climate studies by comparing results of long-term wave statistics, H_{10} hours/year, and extreme wave statistics, H_{100} years/return period
- To determine the effect of using wind data generated by different interpolation methods in third generation wave models (WAVEWATCH III) for storm events
- To determine possible relationships between interpolation methods, wind data, location, wave climate to select the best interpolation method to be utilized in wave modeling studies.

To achieve these aims; two different wave generation models, W61 and WAVEWATCH III, are used for wave analysis of the interpolated wind speed datasets. Long term and extreme wave statistics are applied to the generated wave data in order to calculate the respective wave heights and a basic statistical analysis is conducted to evaluate the performances of the investigated interpolation methods with respect to original input dataset. However, for two of the WAVEWATCH III cases, the performance of the interpolation methods are determined by using buoy data.

In chapter two, literature review on the effect of data resolution in wave models focusing on the Black Sea and studies on the comparison of the performances of interpolation methods for dataset generation and modeling are presented. In chapter three the methodology followed in this thesis with the data used are presented. Detailed information on the wave generation models, interpolation methods that were investigated in this thesis and the statistical parameters used for the comparisons are given. Additionally, long term wave analysis and extreme wave analysis are explained. In chapter four, results obtained from the wave generation models and wave analysis have been merged and analyzed for the long term and extreme events. The comparison of WAVEWATCH III model results using different interpolated wind data and buoy data is presented. All the results are discussed numerically and graphically with the relevant comparison to interpolated wind datasets. Finally, the findings of the study are summarized and recommendations for future research are presented in the concluding chapter.

CHAPTER 2

LITERATURE RESEARCH

2.1. General

The literature presented in this section primarily aims to highlight the importance of resolution of data in wave modeling. As the study focuses on the Black Sea as the area of interest, research on wave modeling of the Black Sea is also summarized. Then, a short summary of the literature on use of interpolation methods and the assessment of their performances is provided. Similarly, research on use of interpolation methods for wind data (including focused research on the Black Sea region) is also presented.

2.2. Effect of Input Resolution on Wave Generation Models

The effects of temporal and spatial resolutions on the wind and wave climates have been studied by several researchers. Lavidas et al. (2017) studied the sensitivity of wave models on wind reanalysis datasets for the Scotland region. In the research, the performances of European Centre for Medium-Range Weather Forecasts (ECMWF) and Climate Forecast System Reanalysis (CFSR) datasets which have different spatio-temporal resolutions have been compared. It had been concluded that even though ECMWF (which have a lower temporal resolution) over performs CFSR for the Scotland region, CFSR dataset (with higher temporal resolution) offers a better simulation of the peak values for extreme analyses.

As mentioned, wind velocity is considered to be the most important parameter for wave analysis and several research were conducted on this subject. In addition to the global scaled studies, several research had focused on the effects of wind data on wave analysis for several different regions. The Black Sea region is a commonly selected area for research due to high coastal activity. In the Black Sea region, Van Vledder G. and Akpınar A. (2015) had conducted research on the sensitivity of the wave models to the wind fields. In the scope of the research, the effects of both temporal and spatial resolutions had been investigated using the SWAN wave model. It had been concluded that the choice of wind fields (CFSR, ECMWF, and MERRA) was very important to obtain an accurate wave analysis. Also, an important finding of the research was the indication that the coarsening of spatial resolution have a greater effect on the wave models than the coarsening of temporal resolution. For inspecting the effects of the temporal resolution of wind fields on wave hindcasting, CFSR datasets (CFSR wind field had been proven to perform better than other wind fields for the inspected stations within the research) with different time steps had been used. From the results, it had been concluded that finer temporal resolutions do not significantly improve the bulk performance (average over all data points) of the SWAN wave model.

This statement is also supported by the results of the research by Erol (2014) on the evaluation of extreme wave statistics for the Western Black Sea Region using meteorological and ECMWF wind datasets. In addition to the 6-hour available ECMWF wind data, Spline interpolation method had been applied in order to obtain an hourly ECMWF wind speed dataset. The hourly wind dataset along with the meteorology data and the 6 hour time step ECMWF data had analyzed by W61 and the results were used to compute the extreme wave statistics in the region. The wave fields obtained from the meteorological wind speeds and hourly ECMWF data were compared to each other and it was concluded that the hourly ECMWF data results in significantly higher wave heights than meteorology dataset. Also, it was noted that the Spline interpolation method, creates storms with longer durations causing higher wave heights. He had transformed the existing hourly ECMWF wind speed data into 6-hour data first and then applied Spline interpolation to form a new interpolated meteorology dataset. The aim was to obtain two datasets both of which was generated with Spline method and confirm the effects of the interpolation method but the new meteorological wind speed dataset did not provide enough storms above the previously determined threshold value. Thus, the effects of the Spline interpolation method on the results could not be confirmed.

Kirezci (2016) studied the performances of third generation wave models SWAN and WAVEWACH III in the Black Sea basin. One of the most important conclusions of this study is that it has been seen that CFSR wind data performs much better than ECWMF wind data in the Black Sea even though CFSR data has a lower spatial resolution. Both SWAN and WAVEWATCH III models performed well after the calibrations were applied using buoy data, it was seen that WAVEWATCH III had performed significantly better than the SWAN model. It was concluded that the disparities between the generated dataset and buoy data was most likely caused by the systematic underestimation of the wave parameters and missing the peak wave heights.

Even though, some studies indicate that the effects of temporal resolution on wave analysis are limited in the Black Sea; generally, the researchers and designers prefer using wind datasets with higher temporal resolutions to provide the most accurate results.

2.3. Previous Research on Comparison of Interpolation Methods

Interpolation methods are a popular approach for increasing the temporal and spatial resolutions of the available datasets. Therefore, the effects of temporal and spatial interpolation methods have been studied for various fields of research. For instance, Robinson and Metternicht (2016) and Addis et al. (2016) focused on the effects of spatial interpolation methods on soil properties, Adhikary et al. (2014) on the effects on the groundwater depth, Güler M. and Kara T. (2014) focused their research on the effects on the modeling temperature and Apaydın et al. (2004) on the effects on the climate data in the Southeastern Anatolian Project (GAP) and many other research.

For the past decade, studies were performed on the comparisons of different interpolation methods for various fields of application to understand the conditions and methods for best performance in terms of accuracy. Lepot et al. (2017) prepared an introductive research; overviewing the interpolation methods in time series, their performance and the resulting uncertainty assessment for different fields such as engineering and academic researches. In total, more than 50 studies have been reviewed by Lepot et al. (2017) under 2 main divisions. These are classified as deterministic methods and stochastic methods. They determined more than 30 statistical parameters used for the evaluation of the performances of interpolation methods. It was concluded that although many research had been conducted on the interpolation methods in time series for many different statistical parameters, the lack of common reference parameters makes conducting comparisons difficult. They pointed out that the ranking of the performance of different interpolation methods could be strongly dependent on the nature of the recorded phenomenon and data. At the end of the research, it was suggested that the limited published studies on the uncertainty calculations and comparative studies may lead to mistakes in uncertainty assessments during calculations and design stages. It is suggested that a comparative study standardizing the methods used for assessing the uncertainties and studies with lexical issues will improve filling the gaps in the literature.

Similar research had been prepared by Li J. and Heap A.D. (2011), reviewing the comparative studies prepared on the performance and impact factors of spatial interpolation methods in environmental sciences. Within the scope of the research over 50 research on the effects of spatial interpolation methods have been reviewed for many different disciplines. It had been concluded that the 70 spatial interpolation methods that had been investigated in the environmental researches, the performances are highly sensitive to the variations in the data.

The research by Güler et al (2016a, 2016b) focuses on the effects of using different interpolation methods for generating wind datasets in the Black Sea. In these studies, NCEP-CFSR dataset was used between years 1979 and 2010 for 10m above the surface. Hourly wind field was downscaled to obtain wind field with a time step of 6 hours and nine different interpolation methods were used to obtain nine different sets of hourly wind fields for 522 points at the Black Sea. The temporal resolution of 6 hours was selected because it is provided temporal resolution of another widely used wind climate database, ECWMF. The generated wind speed datasets were compared with the original hourly wind speed dataset in order to evaluate the performance of each interpolation method. These interpolation methods used in the study were: Linear interpolation, 2nd Degree Lagrange Interpolating Polynomials (LIP-2), Degree Lagrange Interpolating Polynomials (LIP-3), 1-D FFT Interpolation, Piecewise Cubic Hermite Polynomial (PCHP) Interpolation, Cubic Spline Interpolation, Dummy Left (w_0 interpolation) and Right (w_6 interpolation) Interpolation methods. In order to assess the performance of these interpolation methods and to rank their performance with respect to each other, basic statistical analysis was used.

The results were discussed for both long term analysis and extreme events. Long term analysis results indicated that PCHP, Cubic Spline, and Linear Interpolation methods were the best three interpolation methods for the Black Sea basin. For most of the points, PCHP was the best method but for some points at the Southern coastlines Cubic Spline method was more preferable over PCHP. The best interpolation method for wind speeds at the 522 pixels within the Black Sea basin is given in Figure 2.1. Also, it can be seen from Figure 2.2. and Figure 2.3. that the second best and the third best interpolation methods vary between these three interpolation methods. Additionally, the normalized bias indicated that a general overestimation trend of wind speeds exists at the Black Sea basin.

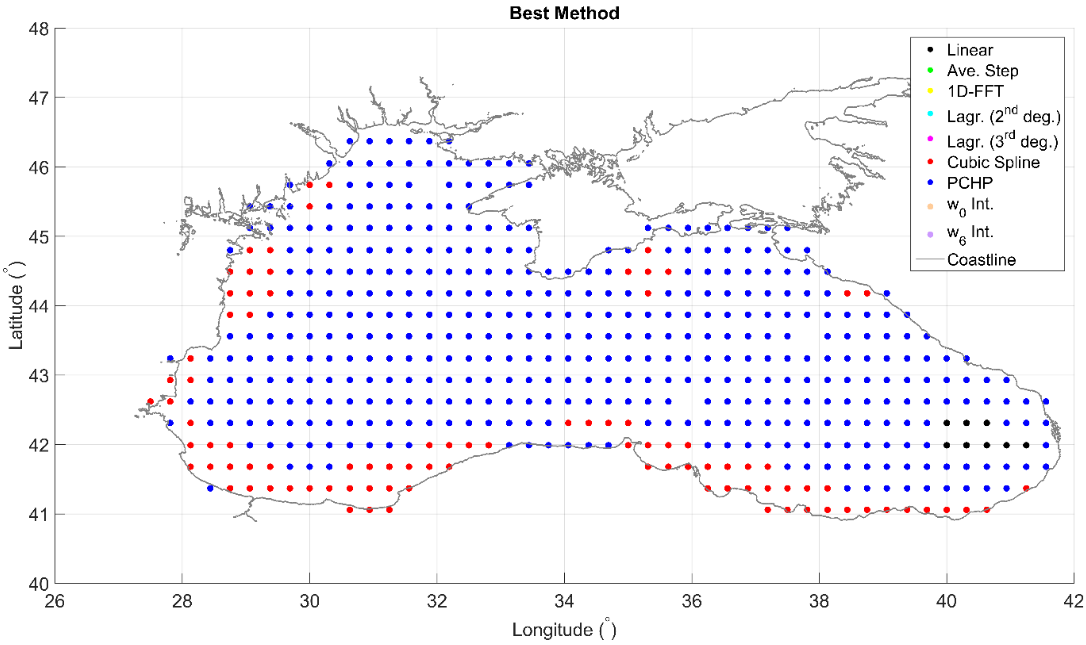

Figure 2.1. The Best Interpolation Method for Long Term Analysis (Güler et al., 2016)

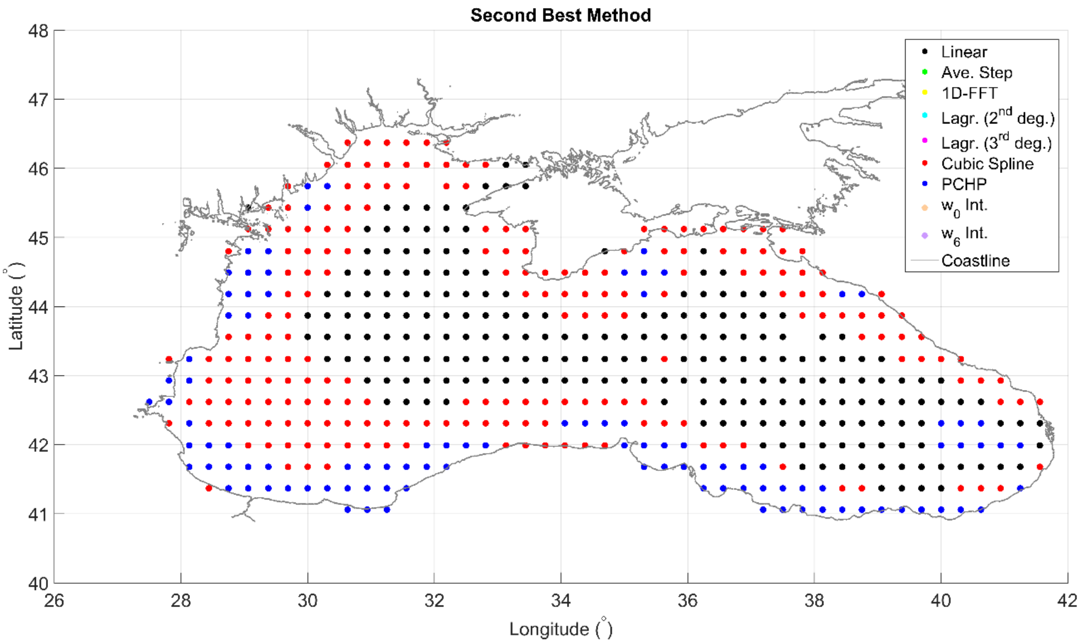

Figure 2.2. The Second Best Interpolation Method for Long Term Analysis (Güler et al., 2016)

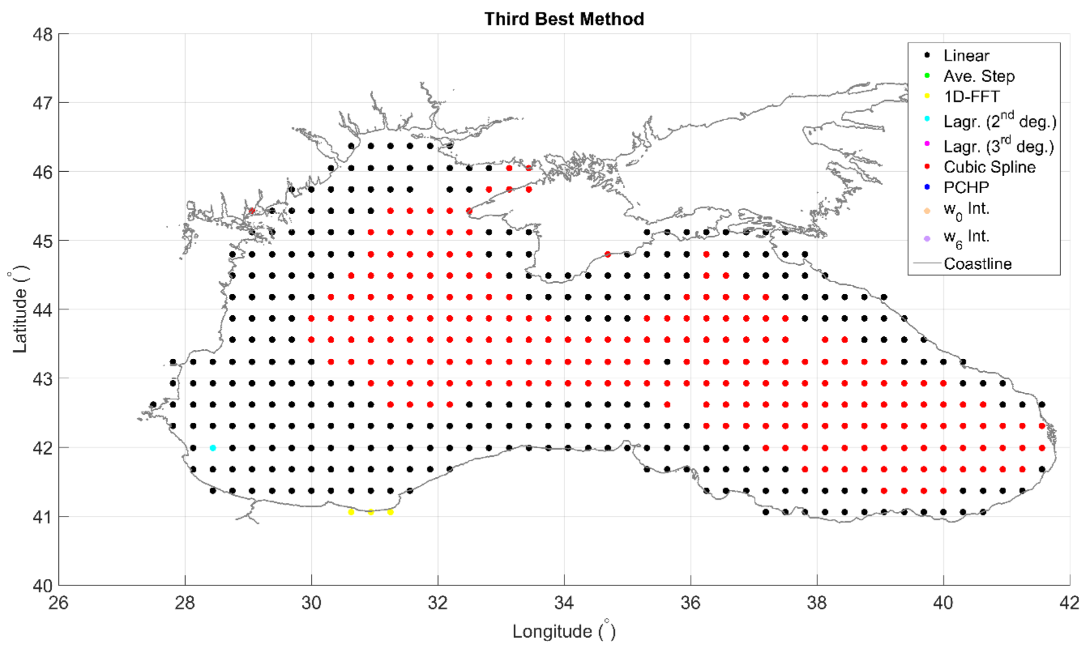

Figure 2.3. The Third Best Interpolation Method for Long Term Analysis (Güler et al., 2016)

For extreme event analysis, one event was chosen for each year, between the years 1979 and 2010, for all 522 pixels investigated. A selection algorithm based on the highest peak wind speeds was developed in order to determine the extreme storm event of each of the years of the respective pixels. Results for extreme event analysis showed that; as it was for long term analysis; PCHP, Cubic Spline and Linear Interpolation methods were the best three methods among the nine that were inspected. Also similar to long term analysis, PCHP performed better compared to other interpolation methods for most of the 522 pixels in the Black Sea basin. Additionally, the normalized bias results showed that both over and underestimation was observed for the interpolated wind speeds.

The results of the investigated statistical parameters for all nine interpolation methods are given in Table 2.1. These parameters include Root Mean Square Error (RMSE), Coefficient of Variation of the Root Mean Square Error (CVRMSE), Mean Average Error (MAE), Normalized Mean Average Error (NMAE), Prediction Skill (PS), Bias and Normalized Bias. Also, it was observed that for both long term analysis and extreme event analysis, using Dummy Left (w_0 interpolation) and Dummy Right (w_6 interpolation) interpolation methods results in the highest errors.

Table 2.1. *Average Statistics for Long Term Wind Analysis (Güler et al., 2016)*

Method/Stat	RMSE (m/s)	CVRMSE	MAE (m/s)	NMAE	PS	Bias (m/s)	Norm. Bias
w_0 Interpolation	1.39	0.25	0.32	0.12	0.71	0.01	0.00
w_6 Interpolation	1.49	0.27	0.36	0.13	0.67	0.01	0.00
Linear Interpolation	0.88	0.16	0.19	0.07	0.89	0.26	0.09
Averaging Step Function Interpolation	1.07	0.20	0.23	0.09	0.84	0.34	0.12
1D-FFT Interpolation	0.94	0.17	0.21	0.08	0.87	0.02	0.01
Lagrange Interpolating Polynomials (2nd degree)	0.90	0.16	0.20	0.07	0.88	0.10	0.04
Lagrange Interpolating Polynomials (3rd degree)	0.95	0.17	0.22	0.08	0.86	0.04	0.01
Piecewise Cubic Hermite Polynomial Interpolation	0.85	0.16	0.19	0.07	0.89	0.15	0.05
Cubic Spline Interpolation	0.85	0.16	0.19	0.07	0.89	0.07	0.03

At the end of the study, it was concluded that the interpolation techniques cause significant differences in predicting the wind velocities. Therefore, it was recommended to select an interpolation technique that is appropriate for the study region to increase the accuracy of the wave climate studies.

CHAPTER 3

METHODOLOGY AND DATA

3.1. Introduction

In this chapter, information related to the methodology followed throughout this research is explained in detail. The input data used for computer models and computations are presented in addition to general information on the computer models used, W61 and WAVEWATCH III. The interpolation methods used in generating wind input is also explained. Additionally, the statistical parameters that are used in order to evaluate the performances of the interpolation methods are defined.

3.2. Background Information

This study is focused on the whole Black Sea which is a large inland sea. It is located at 40° 60’ - 46° 30’ N longitude and 27° 30’ – 41° 45’ latitude. The Black Sea has borders to Turkey, Bulgaria, Romania, Georgia, Russia, and Ukraine. It is connected to the Sea of Marmara, the Dardanelles, the Aegean Sea, and the Mediterranean Sea via the Bosporus and the smaller Sea of Azov via the Kerch Strait. Not including the Sea of Azov, the Black Sea has a surface area of 422 km^2. Some of the major ports are İstanbul, Sinop, Varna, and Odessa. For the countries within the region, the Black Sea is strategically very important. In addition to being an important transportation route linking the Eastern European countries with world markets, there are many petroleum sources in the Western regions. Also, fishing, recreation, and tourism is an important source of income in the region.

Except for the Northwestern and Western areas, the Black Sea has a steep continental slope and very narrow continental shelf. Also, the coasts of the Black Sea are surrounded by large mountainous regions with various layouts, resulting in specific wind patterns in the coastal areas (Arkhipkin et al., 2014 and Akpınar et al., 2016). There are few small islands in the Black Sea, none of which are considered as an obstacle for fetch distance calculations.

Akpınar et al. (2016) had prepared a research on the wind and wave characteristics of the Black Sea region. From the results of the research; it had been deduced that seasonally the largest wind speed, wave height and energy period are observed in the winter and the smallest climate characteristics are observed in the summer season. Also, it had been noted that the highest wind speeds are observed in the western Black Sea region.

3.3. Methodology

In Chapter 1, the main aims of this thesis have been presented and it has been stated that in order to achieve these aims wave generation programs will be used to perform long term and extreme wave statistics. Using the obtained wave data, error analysis will be conducted to evaluate and compare the performances of the investigated interpolation methods.

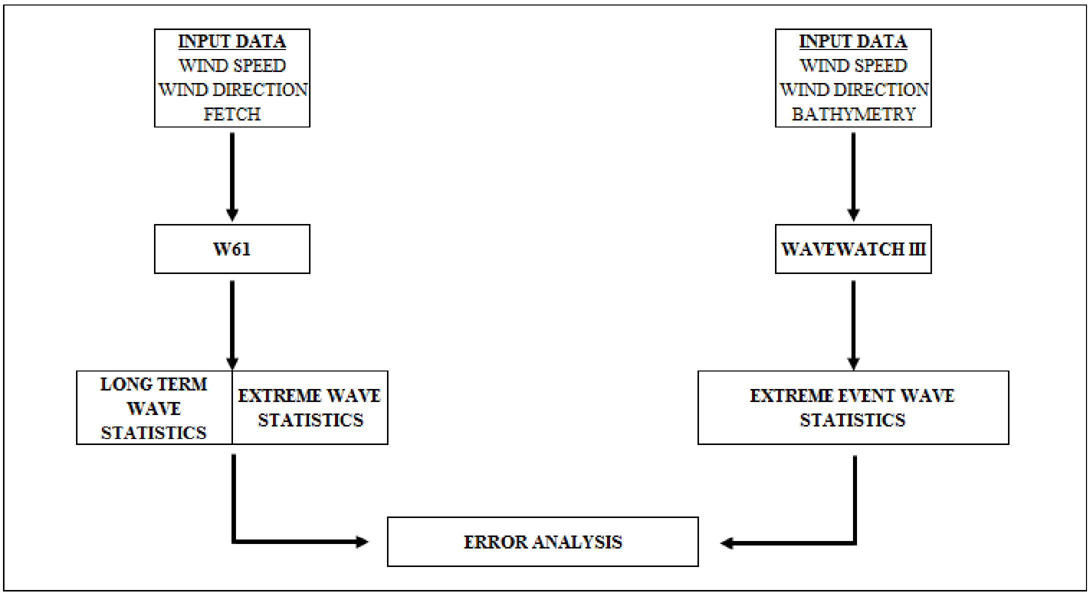

Figure 3.1. Flow of Wave Generation, Wave Statistics and Error Analysis

The complete flowchart of the procedures that are followed for this study is given in Figure 3.1. This study is conducted in two stages based on the two different wave generation models that are used for obtaining the wave characteristics. The first wave generation model used is W61. The W61 model requires wind speed, corresponding wind direction and fetch distances as input data. A secondary computer program called Wind.Exe has been used in order to organize and regroup the necessary input data for W61. Detailed information on the W61 wave generation model and Wind.Exe is given in Section 3.3.2.1.

Using Wind.exe with the fetch distances and hourly wind speed data, input files for W61 have been prepared. For each year between 1979 and 2010, 32 yearly input files for 4 different interpolated datasets and the additional original dataset have been prepared. This process is repeated for each of the selected 25 points. Using the prepared input files W61 analyses are conducted.

The output files obtained from W61 are used for long term and extreme wave analysis. Also for extreme wave analysis, Gumbel distribution is preferred in order to obtain uniform results for comparisons. Detailed information on long term wave analysis and extreme wave analysis is given in Section 3.3.3.

The second wave generation model used in this study is WAVEWATCH III. WAVEWATCH III model uses wind speed, the corresponding wind direction and the bathymetry of the study area as input files. Further detailed information on the WAVEWATCH III wave generation model is given in Section 3.3.2.2.

The necessary input files including the bathymetry data with 0.1°×0.1° spatial resolution and hourly wind speed data files for each interpolation method is prepared for 3 separate storm events in the Black Sea basin. The output time series are graphed, statistically evaluated and compared with the original time series. Since WAVEWATCH III has been used for 3 selected storm events with limited duration, the results obtained are classified under extreme event analysis.

Statistical parameters are calculated and comparison graphs are drawn, to evaluate and compare the performances of the interpolation methods with respect to the original dataset and each other for the results obtained from both W61 and WAVEWATCH III wave generation models. Further information on the various statistical parameters used for error analysis is given in Section 3.3.1.

Wind climate and wave climates for both W61 and WAVEWATCH III have been summarized and discussed in detail numerically and graphically.

3.3.1. Interpolation Methods

Different interpolation methods are used to fill the missing wind speed data in every 6 hours. For instance, wind speed at 01.00, 02.00, 03.00, 04.00 and 05.00 will be interpolated using wind speed at hours 00.00 and 06.00. For all of the interpolation methods explained below; x_0 and x_6 will be used to appoint wind speed values to x_1, x_2, x_3, x_4, and x_5.

3.3.1.1. Linear Interpolation Method

For Linear interpolation method it is assumed that a straight line passes through and. So, all values in-between can be calculated using **Equation 3.1**.

$$x_i = x_0 + i \cdot \frac{x_6 - x_0}{6} \; for\ i = 1, 2, 3, 4\ and\ 5 \tag{3.1}$$

3.3.1.2. Dummy Left (w0) Interpolation Method

Another type of linear interpolation is assuming all missing data to be equal to the left side value. For simplicity, this interpolation method will be referred as Dummy Left interpolation method in this research.

3.3.1.3. Dummy Right (w6) Interpolation Method

Another type of linear interpolation is assuming all missing data to be equal to the right side value. For simplicity, this interpolation method will be referred as Dummy Right interpolation method in this research.

3.3.1.4. Cubic Spline Interpolation Method

For high degree polynomial functions with large datasets, using high order interpolations often results in oscillations at the edges of an interval. This phenomenon was first discovered by Carl David Tolmé Runge, thus named as Runge's Phenomenon. A piecewise polynomial interpolation method called Cubic Spline has been offered as a solution to this problem. Using the Cubic Spline Interpolation method is advantageous because, in addition to being easy to apply, this method produces a smooth curve as a result.

For a function $y = f(x)$ where $[x_i, y_i]$ is for $i = 0, 1, 2, 3 \ldots n$. In total there are $n + 1$ points and n intervals defined. Cubic Spline interpolation method divides this function into n piecewise continuous curves. Each curve is described using a cubic polynomial function with four coefficients. This polynomial function is given in **Equation 3.2**:

$$S_i(x_i) = a_i(x - x_i)^3 + b_i(x - x_i)^2 + c_i(x - x_i) + d_i \\ for\ x \in x_i, x_{i+1} \tag{3.2}$$

n numbered $S_i(x)$ piecewise cubic functions together form $S(x)$ spline curve. For each piecewise $S_i(x)$ curve there are four unknown coefficients. So, in order to form a complete $S(x)$ spline curve, there are four conditions needs to be satisfied for all piecewise curves.

The conditions to satisfy continuity in the piecewise curve is given in **Equation 3.3**:

$$S'_{i-1}(x_i) = S'_i(x_i)\ and\ S''_{i-1}(x_i) = S''_i(x_i) \tag{3.3}$$

As can be seen from the polynomial $S_i(x)$, cubic splines are two times differentiable functions. So, they cannot be used for higher derivatives than second. Güler et al. (2016a, 2016b), cubic splines were applied using the instructions described by Boor (1978) and Kahaner et al. (1989). According to this, it was preferred to use the condition referred to as not-a-knot end condition as the extra end condition. From this point on Cubic Spline Interpolation method will be referred as the Spline method.

3.3.1.5. Piecewise Cubic Hermite Polynomial (PCHP) Interpolation Method

Piecewise Cubic Hermite Polynomial interpolation method is another type of Spline with only one continuous derivative instead of two derivatives. As a result, PCHP does not form a curve as smooth as Spline method. Güler et al. (2016a, 2016b), cubic splines were applied using the instructions described by Kahaner et al. (1989). From this point on Piecewise Cubic Hermite Polynomial (PCHP) method will be referred as the Hermite method.

3.3.2. Wave Generation Models

In this research two main wave generation models have been used for wave generation. These models are W61 and WAVEWATCH III. In addition to these wave generation programs, computer programs such as AutoCAD and MATLAB were also used to analyze the wave characteristics obtained from the wave models.

3.3.2.1. W61 Wave Model

W61 is a wave generation computer program developed by METU, Coastal Engineering Department. The program uses a specially organized yearly wind speed data file as an input. These input files are prepared using another computer program, Wind.exe.

Wind.exe requires hourly wind speed data with the fetch distances for 16 directions for each specific location. The program uses these inputs to reorganize and form consecutive storm events for each year separately. The storm event formations are controlled by 3 parameters which can be defined by the user. These parameters are: minimum storm velocity, wave height group interval, and period group interval. For this research minimum storm velocity is determined as 3 m/s, wave height group interval as 0.40 meters and period group intervals as 0.40 seconds. An example input file obtained from Wind.exe is given in Figure 3.2. The output files that Wind.exe includes storm start and end dates, storm duration, hourly direction of the wind and hourly wind speed.

```
    0     2     1 1979     6     7     1 1979   126
18 43 18 49 18 52 18 52 19 59 20 77 20 60 21 61 21 61 22 68 23 84 24106
25140 25159 25150 25133 25117 25 98 26103 26107 26111 26111 26111 25116
26122 26136 26144 25141 25135 25131 25135 25133 25126 25122 25117 25111
26120 26122 25120 25112 25103 24 95 24 92 24 96 23105 23109 23112 23112
24 90 23 95 23109 23115 23118 23118 22105 22105 22112 22110 22107 22106
22106 21102 21102 21100 20103 20109 20108 20109 20117 20128 20133 20132
20124 19128 19135 19143 19147 19141 19112 19112 19 93 21 51 24 72 24108
25109 24109 24115 24115 24113 24107 24 81 24 82 23 86 23 92 23 96 23 98
23 71 23 72 23 84 23 83 23 84 23 82 23 79 23 73 23 65 23 66 23 64 23 61
23 49 23 59 23 56 23 53 23 56 24 63 24 50 25 60 25 65 25 70 25 73 26 74
26 82 26 86 26 90 26 88 26 87 26 86
```

Figure 3.2. Example Input File W61

Using the yearly input files prepared by Wind.exe, W61 will prepare individual H_s and T_s files for each year with dominant wave directions, maximum wave heights with corresponding dominant wave direction for each year and wave distribution with respect to the propagation directions for each year. The obtained results will be used for long term wave analysis and extreme wave analysis.

3.3.2.2. WAVEWATCH III – 3rd Generation Wave Model

WAVEWATCH III (Tolman 1997, 1999a, 2009) is a 3rd Generation Wave Model developed at NOAA, NCEP. The first version of the model, WAVEWATCH, was developed at Delft University of Technology (Tolman 1989, 1991a) and the second version of the model, WAVEWATCH II, was developed at NASA, Goddard Space Flight Center. In this study, WAVEWATCH III version 4.18 is used.

Compared to the previous versions WAVEWATCH III uses governing equations, the model structure, the numerical methods, and the physical parameterizations. NOAA describes that WAVEWATCH III solves the random phase special action density balance equations for wavenumber-direction spectra.

In deep water conditions, such as in this study, WAVEWATCH III uses wind-wave interaction, white capping dissipation, and nonlinear wave interaction as source terms. For both wind-wave interaction and white capping, there are 4 available approaches defined for WAVEWATCH III and 3 different approaches for nonlinear wave interaction. Kirezci (2016) had analyzed and compared these approaches. In this thesis, the most suitable approaches for the Black Sea region determined by Kirezci (2016) are applied.

For wind-wave interaction ST4 approach has been chosen. This approach is based on the study of Ardhuin et al. (2010) and accepts that the waves start breaking when the nondimensional spectra exceed a threshold value. Secondly, for white capping dissipation again a wave-turbulence interaction term (ST4) which is based on Teixeira and Belcher (2002) and Ardhuin and Jenkins 2006) is preferred above other approaches. For nonlinear wave interaction, the Discrete Interaction Approximation (DIA) approach with nonlinear filters applied (NLS) is selected (Tolman 2008b, 2011a).

There are different bottom friction approaches available in WAVEWATCH III. In this study, for bottom friction, JONSWAP parameterization of Hasselmann et al. (1973) is used. The JONSAWP bottom friction (c_b) is chosen as c_b = 0.038 m^2s^{-3} for swell dissipation and c_b = 0.067 m^2s^{-3} for depth limited wind-sea conditions. (Bouws and Komen, 1983)

Additionally, for more accurate results, calibrations proposed by Kirezci (2016) are applied. This calibration values are given in Table 3.1.

Table 3.1 *After Calibration and Default Values of the Selected Parameters (Kirezci, 2016)*

Source Term	Parameter	Variable Name in WW3	ST4NLS (recommended values)	ST4NLS (values used in calibration set)
Wind- Wave Interaction	Z_{wnd}	ZWIND	10	10
	β_{max}	BETAMAX	1.52	1.75
	z_α	ZALP	0.06	0.04
	p_{in}	SINHTP	2	1.7
Swell	s	SWELLFPAR	1	1
	s1	SWELLF	0.8	0.8
	s2	SWELLF2	-0.018	-0.018
	s3	SWELLF3	0.015	0.015
Dissipation	C_{ds}^{sat}	SDSC2	-2.20E-05	-2.60E-05
	C_{cu}	SDSCUM	-0.4034	0
	Br	SDSBR	9.00E-04	1.20E-03
	C_{turb}	SDSC5	0	0
	Δ_θ	SDSDTH	80	100
Non-linear İnteractions (DIA)	λ	LAMBDA	0.25	0.25
	Cnl4	NLPROP	2.50E+07	2.50E+07
NLS Filter	α_{34}	A34	0.05	0.05
	C_{nlf}	FHFC	1.00E+10	1.00E+10
	S_{max}	DNM	0.25	0.25
	c_1	FC1	1.25	1.25
	c_2	FC2	1.5	1.5
	c_3	FC3	6	6

The output parameters offered by WAVEWATCH III, can be selected by the user including; the water depth, wind speed, wind direction, significant wave height (H_s), wave direction or wave period.

During the WAVEWATCH III analysis, two different interpolation methods are available to the users for controlling both temporal and spatial resolutions. These interpolation methods are: Linear Interpolation (WNT1) and Approximate Quadratic Interpolation (WNT2). Since one of the main aims of this study is to compare the performances of different interpolation methods, additional interpolations which may damage the results are not desirable. So, in this study, for both the input and the output files the time steps are chosen as 1 hour in order to avoid any additional interpolations during the WAVEWATCH III analysis.

3.3.3. Wave Statistics

For the design of coastal structures, the design wave characteristics have to be determined. The hindcasted wave data needs to be statistically analyzed in order to determine the design wave characteristics. The long term analysis and extreme wave analysis together define the wave climate statistics.

3.3.3.1. Long Term Wave Statistics

The main purpose of long term wave statistics is to express all recorded/hindcasted wave events throughout years with statistical distribution functions. The distributions vary for different directions, thus forming conditional distributions of wave heights for various directions. The analysis results are used to determine the layouts of harbor/marina designs.

The cumulative number of occurrences of wave heights are classified according to the wave propagation directions and the cumulative exceedance probability of deep water significant wave height, H_{s0}, calculated using **Equation 3.4**.

$$Q(> H_{s0}) = exp[(H_{s0} - B)/A] \tag{3.4}$$

In equation 3.6, $Q(> H_{s0})$ is the cumulative exceedance probability of a deep water significant wave height, H_{s0}. Using this equation $Q(> H_{s0})$ and H_{s0} are plotted on a semi-log graphical paper (H_{s0} on normal and $Q(> H_{s0})$ on a logarithmic scale) to form a straight line, of which A indicates the slope and intercept of B when $Q(> H_{s0})$ is the horizontal axis. The cumulative wave numbers are calculated and classified using MATLAB.

The significant wave heights for the long term wave heights are defined in the hourly exceedance probability per year format. The corresponding significant periods have been calculated using the steepness (H/L) and **Equation 3.5**.

$$L = 1.56 \times T^2 \tag{3.5}$$

3.3.3.2. Extreme Wave Statistics

Extreme wave probability density distributions are determined using the highest significant wave height of each year. Wave direction is not a part of the computations, as opposed to the long term analysis, but it is generally assumed that the peak wave height for each year comes from the dominant wave direction. Extreme wave statistics are used in the design of breakwaters or platforms.

There are several different probabilistic functions to determine the design wave heights for extreme wave statistics. Wind and Wave Atlas for Turkish Coasts (Türkiye Kıyıları Rüzgar ve Derin Deniz Dalga Atlası) use the Gumbel probabilistic density distribution. Özyurt G. and Özbahçeci B.Ö. (2008) have evaluated and compared different probabilistic functions for extreme events in order to determine the best fit for Turkish coasts. The Gumbel function along with the LogNormal distribution had been proven to be the best fit for most of the investigated points but it also had been observed that other distribution functions came out as the best fits for minority of the points.

Since this study is based on comparison purposes between different interpolation methods, it is aimed to not insert any other variables that may affect the comparisons. Thus, it has been decided to use Gumbel (Fisher Tippet Type 1-b) distribution developed by Gringorten (1963), for all of the extreme wave analyses.

After rearranging the hindcasted wave heights in descending order (n number of years), **Equation 3.6** is applied to the ith number of the waves with α = 0.44 and β = 0.12 according to Gumbel (FT1-b).

$$F_i = 1 - \frac{i - \alpha}{n + \beta} \tag{3.6}$$

After computing F_i for all years, Least Square Method is applied for the fitting procedure using **Equation 3.7**.

$$X = A \times Y + B \tag{3.7}$$

Reduced variate, Y, is computed using **Equation 3.8** for Gumbel distribution.

$$Y = -ln[-\ln(F)\,] \tag{3.8}$$

In extreme wave statistics, the design wave height is computed according to the exceedance probability according to the previously determined return period. For instance; the return period may be selected as 5 years, 10 years, 50 years or 100 years.

3.3.4. Statistical Parameters for Comparison

In order to evaluate the performances of different interpolation methods and to compare them with each other several statistical parameters are used. Güler at al. (2016a, 2016b) have offered a simplistic approach based on basic numerical and statistical knowledge. This research will pursue the same approach.

3.3.4.1. Mean Absolute Error (MAE)

Mean Absolute Error (MAE) is one of the most commonly used error calculations for time-series analysis. MAE is calculated using **Equation 3.9**. When it is being used for comparison with Relative Absolute Error, MAE is reported in percent. Estimations are deemed better if the error is lower.

$$MAE = \frac{\sum_{i=1}^{m} \left| x_{true,t} - x_{prediction,t} \right|}{m} \tag{3.9}$$

3.3.4.2. Relative Absolute Error (Absolute Percent Error)

Relative Absolute Error is used for determining the divergence of the predicted value with respect to the true value. Relative Absolute Error is calculated using **Equation 3.10**. Relative Absolute Error is reported in percent. Estimations are deemed better if the error is lower.

$$R.Error = \frac{\left|x_{true,t} - x_{prediction,t}\right|}{x_{true,t}} \cdot 100 \tag{3.10}$$

3.3.4.3. Coefficient of Variation Root Mean Square Error (CVRMSE)

Root Mean Square is defined as a measure of the residuals between the model predictions and measured observations, where larger numbers indicate greater variance (Bryant et al., 2016). CVRMSE is developed in order to eliminate scale dependencies. The CVRMSE is calculated using **Equation 3.11** (Yozgatlıgil et al., 2013).

$$CVRMSE = \frac{RMSE}{\overline{x_{true}}} = \frac{\sqrt{\sum_{i=1}^{m}(x_{true,t} - x_{prediction,t})^2/m}}{\overline{x_{true}}} \tag{3.11}$$

3.3.4.4. Prediction Skill (PS)

Prediction Skill is a statistical parameter that measures the predictive skill. The closer PS values to 1 indicate higher predictive skill. The PS is calculated using **Equation 3.12**.

$$PS = 1 - \frac{\sigma^2(x_{true} - x_{predicted)}}{\sigma^2(x_{true})}\ where\ \sigma^2\ is\ the\ variance \tag{3.12}$$

3.3.4.5. Scatter Index (SI)

Scatter Index can be described as a normalized measure of error. As SI values decrease, the performance of the estimations increases. **Equation 3.13** is used to calculate the scatter index.

$$SI = \frac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}(x_{true,t} - x_{prediction,t})^2}}{\overline{x_{true}}} \tag{3.13}$$

3.3.4.6. Normalized Bias

Bias can be described as a representation of the mean error of the series. In order to eliminate scale dependencies, normalized bias was used. If the bias value is positive it means that the predicted series overestimates the results and if the value is negative it means that the predicted series underestimate the results. **Equation 3.14** is used to calculate the normalized bias.

$$Normalized\ Bias = \frac{\sum_{i=1}^{m}(x_{true,t} - x_{prediction,t})^2}{\overline{x_{true}}} \tag{3.14}$$

3.3.4.7. Variance Ratio

Each time-series displays a change in variability. Variance Ratio represents the ratio of this change in the variability for two-time series. Equation 3.15 is used to calculate the variance ratio.

$$Variance\ Ratio = \frac{\sigma^2(x_{true})}{\sigma^2\left(x_{prediction}\right)} \tag{3.15}$$

$$where\ \sigma^2\ is\ the\ variance$$

3.4. Datasets

The main required datasets for this research are the original and interpolated wind speed and wind direction datasets. These datasets are obtained from Güler et al. (2016a, 2016b). In addition to the wind data, as it has been explained in Section 3.3.2, fetch distances are needed for W61 models and the bathymetry of the study area is needed for the WAVEWATCH III wave generation model.

3.4.1. Wind Climate

Climate data is commonly chosen as an investigative topic, in order to evaluate and compare the effects of interpolation methods for both temporal and spatial resolutions.

This is due to the fact that climate data is vital for many disciplines from coastal engineering to geoscience.

There are many different globally scaled wind speed datasets available prepared by different sources and using different models. Measuring wind characterization parameters overseas and oceans can be difficult. Anemometers located at small island weather stations, on ships and on buoys floating in the sea are the primary measurement instruments (Remote Sensing Systems). Also, satellite dataset have been proven to be very advantageous over the past decades. Generally, in-situ measurements are considered to be more reliable than reanalysis but in-situ measurements are usually very limited and localized so in most cases reanalysis models are needed.

Reanalysis can be defined as a climate or weather model simulation that is prepared data assimilations of past historical observations (Schimidt, 2011). Some of the most well-known wind climate reanalysis models are, Modern Era Retrospective-Analysis for Research and Applications (MERRA), NCEP-NCAR, ERA-40, ERA-Interim, NCEP Climate Forecast System Reanalysis (CFSR), Global Land Data Assimilation System (GLDAS). Each of these reanalysis models have different temporal and spatial resolutions and covers different time spans. Temporal resolutions and time spans for each of the reanalysis models are given in Table 3.2. Hourly wind data is preferred by designers since lower temporal resolutions provide much reliable results.

Table 3.2. *Temporal Resolutions and Time Spans for Reanalysis Models*

Reanalysis Model	Temporal Resolution	Time Span
MERRA 2	Hourly	1979 - 2016
NCEP-NCAR	Monthly/Hourly	1981 - 2010
ERA-40 (ECWMF)	6-Hours	1957 - 2002
ERA-Interim (ECWMF)	6-Hours	1989 - present
NCEP-CFSR	Hourly	1979 - 2011
GLDAS	3-Hours	1979 - present

3.4.1.1. Wind Input Used in Modelling

In this study, NCEP Climate Forecast System Reanalysis (CFSR) dataset is used to generate the wind input both as the original dataset and for the interpolated datasets for the period of January 1979 to December 2010. The NCEP Climate Forecast System Reanalysis (CFSR) is one of the products of Climate Forecast System (CFS) on global domain. The CFS model is a representation of the global interactions between the Earth's oceans, land, and atmosphere and collects many variables using observations from many sources such as air balloons, aircraft, and satellites. CFSR dataset was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over 32 year period of record. The output time resolution is hourly with a horizontal resolution of 0.5 latitudes and 0.5 longitudes.

Among the 522 points studied by Güler et al. (2016a, 2016b), 25 of them have been selected for further wind climate investigation and wave analysis. All of the points that have been selected, follow the coastline of the Black Sea. Selected points are given in Figure 3.3. In Figure 3.3 it can be observed that 13 of the selected 25 points are located in the coasts of Turkey.

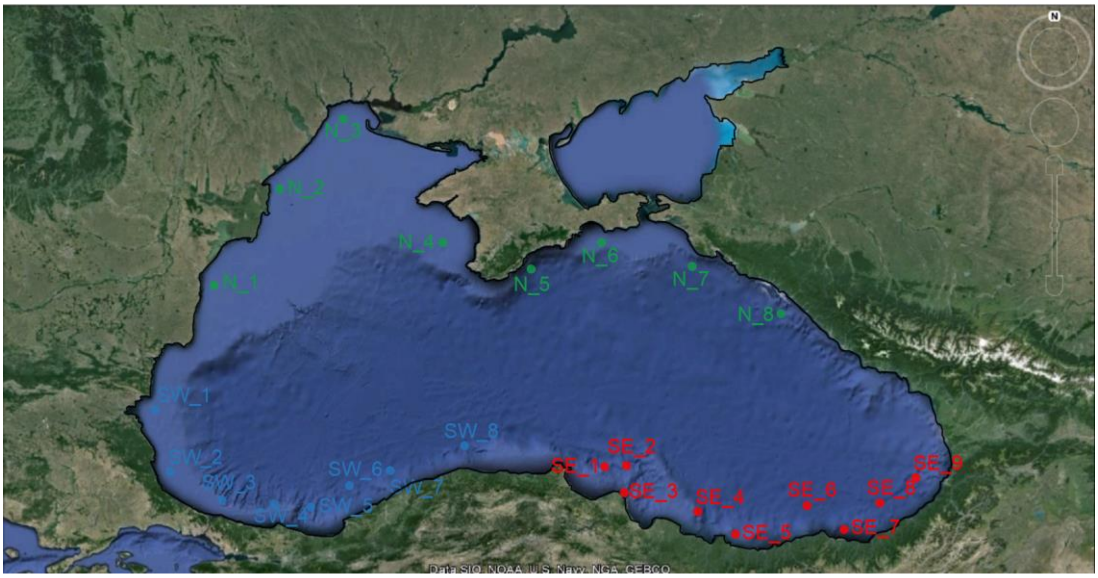

Figure 3.3. Selected 25 points within the Black Sea

Selected points have been categorized according to their location in the Black Sea. There are 3 main sub-regions determined for this study. These are: South West Region, South East Region and, North Region. Both South West Region (blue dots) and North Region (green dots) contain 8 points whereas South East Region (red dots) contains 9 points (Figure 3.3). The coordinates of the selected points are given in Table 3.3.

Table 3.3. *The coordinates of the selected points within the Black Sea basin*

POINT	REGION	LATITUDE	LONGITUDE
SW_1	SOUTH WEST REGION OF BLACK SEA	42.62 ° N	28.13° E
SW_2		41.68 ° N	28.44° E
SW_3		41.37 ° N	29.38° E
SW_4		41.37 ° N	30.31° E
SW_5		41.37 ° N	30.94° E
SW_6		41.68 ° N	31.56° E
SW_7		41.99 ° N	32.19° E
SW_8		42.31 ° N	33.44° E
SE_1	SOUTH EAST REGION OF BLACK SEA	41.99 ° N	35.94° E
SE_2		41.99 ° N	35.31° E
SE_3		41.68 ° N	36.25° E
SE_4		41.37 ° N	37.50° E
SE_5		41.06 ° N	38.13° E
SE_6		41.37 ° N	39.38° E
SE_7		41.06 ° N	40.00° E
SE_8		41.37 ° N	40.63° E
SE_9		41.68 ° N	41.25° E
N_1	NORTH REGION OF BLACK SEA	44.18 ° N	29.06° E
N_2		45.43 ° N	30.00° E
N_3		46.37 ° N	31.25° E
N_4		44.80 ° N	33.13° E
N_5		44.49 ° N	34.69° E
N_6		44.80 ° N	35.94° E
N_7		44.49 ° N	37.50° E
N_8		43.87 ° N	39.06° E

Reviewing the results of Guler et al (2016a, 2016b) for these 25 points, it is observed that the best, the second best and the third best interpolation methods vary between the PCHP, Cubic Spline, and Linear interpolation methods. Moreover, the interpolation method that ranks the worst among others is either Dummy Right or Dummy Left interpolation methods. So, it is decided that interpolation methods with the best, the second best, the third best and the worst wind analysis performance will be used for further investigation of wave analysis. The ranking of the performance of the determined interpolation methods is given in Table 3.4.

Table 3.4. *Performance Ranking of Interpolation Methods (Güler et al., 2016b)*

POINT	REGION	WIND			
		BEST	2ND BEST	3RD BEST	WORST
SW_1	SOUTH WEST REGION OF BLACK SEA	HERMITE	SPLINE	LINEAR	DUMMY RIGHT
SW_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SW_3		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SW_4		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SW_5		SPLINE	HERMITE	LINEAR	DUMMY LEFT
SW_6		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SW_7		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SW_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT
SE_1	SOUTH EAST REGION OF BLACK SEA	SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SE_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SE_3		SPLINE	HERMITE	LINEAR	DUMMY LEFT
SE_4		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SE_5		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SE_6		HERMITE	LINEAR	SPLINE	DUMMY RIGHT
SE_7		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SE_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT
SE_9		HERMITE	LINEAR	SPLINE	DUMMY RIGHT
N_1	NORTH REGION OF BLACK SEA	SPLINE	HERMITE	LINEAR	DUMMY RIGHT
N_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT
N_3		HERMITE	SPLINE	LINEAR	DUMMY RIGHT
N_4		HERMITE	SPLINE	LINEAR	DUMMY RIGHT
N_5		HERMITE	SPLINE	LINEAR	DUMMY RIGHT
N_6		HERMITE	SPLINE	LINEAR	DUMMY RIGHT
N_7		HERMITE	SPLINE	LINEAR	DUMMY RIGHT
N_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT

3.4.2. Fetch Distance

The sea area over which the wind blows to create waves is called the fetch The fetch distance is one of the main parameters that control the wave generation thus is a required input for W61 models. Effective fetch distances are calculated using **Equation 3.16** for 7.5° intervals.

$$F_{eff} = \frac{\sum F_i \times cos^2 \gamma_i}{\sum \cos \gamma_i} \tag{3.16}$$

Since all of the points selected for analysis are close to the shore, fetch values for one or more directions are eliminated from the input files. Short fetch distances (approximately fetch distance values that are smaller than 10% of the maximum fetch distance for each point) are eliminated. Fetch distances (km) for each sub-region is given in Table 3.5, Table 3.6 and Table 3.7. The fetch distances that have not been included in the analyses are indicated with grey coloring.

Table 3.5. *Fetch Distances for South West Sub-Region of Black Sea*

	SOUTH WEST REGION OF BLACK SEA							
	SW_1	**SW_2**	**SW_3**	**SW_4**	**SW_5**	**SW_6**	**SW_7**	**SW_8**
NORTH **N**ORTH **E**AST (NNE)	300.1	460.2	532.2	533.1	523.2	467.3	397.5	337.5
NORTH **E**AST (NE)	482.1	631.7	640.9	610.4	585.6	531.1	475.2	430.2
EAST **N**ORTH **E**AST (ENE)	707.9	732.3	719.1	572.7	431.8	492.6	558.7	547.6
EAST (E)	771.7	574.2	487.1	310.4	155.3	238.5	338.3	490.4
EAST **S**OUTH **E**AST (ESE)	540.9	211.3	109.1	84.6	44.1	41.1	50.6	252.7
SOUTH **E**AST (SE)	253.2	104.3	46.0	55.3	40.4	31.9	34.1	62.2
SOUTH **S**OUTH **E**AST (SSE)	171.6	52.8	28.5	33.5	38.3	30.5	33.1	41.7
SOUTH (S)	110.7	36.5	22.1	24.9	36.0	37.5	39.6	35.6
SOUTH **S**OUTH **W**EST (SSW)	66.7	30.5	20.3	26.9	36.7	60.8	*64.7*	43.7
SOUTH **W**EST (SW)	45.6	29.8	24.1	38.4	42.6	96.0	123.5	121.1
WEST **S**OUTH **W**EST (WSW)	45.5	30.8	38.3	66.2	79.0	162.7	225.0	290.2
WEST (W)	44.8	34.2	*71.3*	128.9	168.5	260.5	321.4	429.3
WEST **N**ORTH **W**EST (WNW)	37.8	40.9	121.3	209.5	268.0	329.7	369.5	453.6
NORTH **W**EST (NW)	34.8	74.7	182.9	268.2	326.1	366.2	393.7	465.3
NORTH **N**ORTH **W**EST (NNW)	52.6	133.1	263.4	349.0	408.5	439.9	453.1	444.0
NORTH (N)	102.3	270.7	413.8	479.9	504.6	480.5	440.4	354.7

Table 3.6. *Fetch Distances for South East Sub-Region of Black Sea*

	SOUTH EAST REGION OF BLACK SEA								
	SE_1	**SE_2**	**SE_3**	**SE_4**	**SE_5**	**SE_6**	**SE_7**	**SE_8**	**SE_9**
NORTH **N**ORTH **E**AST (NNE)	384.8	404.0	377.2	340.8	338.8	237.5	227.9	160.2	80.5
NORTH **E**AST (NE)	362.9	397.0	380.9	337.5	325.6	223.2	183.6	122.3	53.5
EAST **N**ORTH **E**AST (ENE)	416.6	461.3	419.0	343.9	279.3	201.1	111.1	84.7	38.0
EAST (E)	420.7	456.9	376.9	266.4	150.6	150.8	47.7	52.1	27.5
EAST **S**OUTH **E**AST (ESE)	295.3	264.1	211.1	142.6	40.1	97.7	23.5	33.8	23.7
SOUTH **E**AST (SE)	142.6	82.7	80.0	64.4	22.9	61.8	15.9	27.2	25.0
SOUTH **S**OUTH **E**AST (SSE)	64.4	41.5	43.9	39.7	15.6	39.6	9.9	28.1	27.9
SOUTH (S)	37.3	31.5	34.8	33.7	13.5	34.3	8.3	32.7	36.4
SOUTH **S**OUTH **W**EST (SSW)	39.3	24.4	23.7	32.9	13.6	43.2	9.8	45.4	62.0
SOUTH **W**EST (SW)	53.0	20.4	16.4	37.1	16.5	75.6	12.1	69.0	124.0
WEST **S**OUTH **W**EST (WSW)	64.5	18.4	13.1	52.1	22.1	144.1	19.5	173.9	277.3
WEST (W)	331.3	14.9	114.7	190.2	168.1	520.2	348.1	600.7	687.8
WEST **N**ORTH **W**EST (WNW)	590.5	264.2	419.8	528.6	545.4	758.4	682.6	842.0	814.3
NORTH **W**EST (NW)	567.4	494.0	611.8	658.5	715.8	630.0	672.4	633.2	516.1
NORTH **N**ORTH **W**EST (NNW)	431.0	448.9	474.9	486.0	520.7	418.2	429.1	344.5	243.0
NORTH (N)	383.9	374.7	387.2	394.6	400.2	291.1	289.9	209.5	123.6

Table 3.7. *Fetch Distances for North Sub-Region of Black Sea*

	NORTH REGION OF BLACK SEA							
	N_1	**N_2**	**N_3**	**N_4**	**N_5**	**N_6**	**N_7**	**N_8**
NORTH **N**ORTH **E**AST (NNE)	180.4	87.7	34.8	47.7	*50.8*	30.7	25.6	24.4
NORTH **E**AST (NE)	311.7	151.5	36.4	47.7	97.3	53.2	31.8	22.6
EAST **N**ORTH **E**AST (ENE)	421.5	207.4	37.0	41.9	184.3	88.9	41.9	25.1
EAST (E)	706.6	351.7	*53.5*	36.4	346.5	174.5	80.2	34.8
EAST **S**OUTH **E**AST (ESE)	750.2	616.1	103.4	111.4	522.2	381.7	250.6	142.7
SOUTH **E**AST (SE)	487.6	700.3	352.8	292.0	545.8	518.8	409.2	276.2
SOUTH **S**OUTH **E**AST (SSE)	370.6	496.1	524.2	411.5	403.4	470.1	431.1	330.7
SOUTH (S)	333.2	478.8	571.0	360.3	318.8	389.0	387.9	333.5
SOUTH **S**OUTH **W**EST (SSW)	231.2	340.6	508.7	432.1	356.3	398.7	374.9	345.5
SOUTH **W**EST (SW)	107.8	133.2	292.1	503.8	496.3	555.7	508.1	432.9
WEST **S**OUTH **W**EST (WSW)	41.2	18.3	90.7	454.6	509.7	530.0	636.3	687.8
WEST (W)	34.3	15.3	*47.6*	343.5	262.9	253.0	474.3	741.4
WEST **N**ORTH **W**EST (WNW)	36.5	17.4	*41.2*	279.7	33.3	59.4	176.2	414.6
NORTH **W**EST (NW)	40.1	23.8	38.9	213.0	31.8	45.9	107.4	143.8
NORTH **N**ORTH **W**EST (NNW)	46.6	31.0	35.5	120.2	33.8	34.6	58.3	53.7
NORTH (N)	62.2	39.3	33.5	55.6	37.2	26.8	30.1	32.2

3.4.3. Sea Bottom Topography (Bathymetry)

National Ocean Service (NOAA) defines bathymetry as the study of the beds and floors of water bodies including the oceans, rivers, streams, and lakes. Topographical properties of the study areas are defined using grid systems for numerical models such as WAVEWATCH III. WAVEWATCH III requires a bathymetry grid and a land/sea mask grid. For this thesis, both of these grids are obtained from the research by Kirezci (2016).

Kirezci (2016) had retrieved the bathymetric data from the study of "Global Bathymetric Prediction for Ocean Modeling and Marine Geophysics" by Sandwell and Smith (1996). This extensive oceanography study was prepared to combine all available depth soundings collected for 30 years with high-resolution marine gravity information provided by the oceanography and geophysics.

Kirezci (2016) had studied the effects of spatial resolution on WAVEWATCH III with bathymetry data prepared with the finer grid (0.05° × 0.05°) and with the coarser grid (0.1° × 0.1°) and concluded that the changes between two cases are small. Thus, in this study, the Black Sea is modeled with 0.1° × 0.1° (151 × 71 in mesh size) spatial resolution using 1-minute bathymetric data.

The land/sea mask grid defining the boundary condition of the Black Sea is also obtained from Kirezci (2016). The land/sea mask grid is given in Figure 3.4. Land points in which there are no wave action is observed is represented with "0" and regular sea points are represented with "1". Also during the WAVEWATCH III analysis, active boundary points defining the transitions from land to sea are represented with "2" whereas points excluded are represented with "3"

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Figure 3.4. Land/Sea Mask Grid for the Black Sea

CHAPTER 4

RESULTS AND DISCUSSION

4.1. General

In this chapter, the wind and wave climate for the selected 25 points is discussed and results obtained from the W61 and WAVEWATCH III models are presented. Using the generated wave sets, long term wave analysis and extreme wave analysis results are introduced and summarized both numerically and graphically. Also, basic statistical analysis is used to evaluate the performances of the interpolation methods for long term wave analysis and extreme wave analysis. Additionally, the performances of these interpolation methods for wave analysis are compared with their wind analysis counterparts.

4.2. Wind Climate

Wind datasets which were generated using the selected interpolation methods and the statistical analysis for these datasets, for the inspected 25 points within the Black Sea, were obtained from Güler et al. (2016a, 2016b).

All of these interpolation methods are being effectively used in different fields with success. For instance, Güler et al. (2016a, 2016b) have used these interpolation methods to increase the temporal resolution of 6 hours wind speed to hourly wind speeds and evaluated the performance of these methods for wind analysis. As it has been explained each interpolation method follows a different mathematical approach to artificially create new data within two known values. The graphical comparison of these five interpolation methods is given in Figure 4.1. In addition to the Linear interpolation; Dummy Right and Dummy Left interpolations also follow a linear approach as it is seen from the graph. On the other hand, it is clearly seen that Spline and Hermite interpolation methods form a polynomial curve in order to predict the missing data. If the graph is inspected in four sections, each having a time step of 6 hours; it is observed that twice the interpolation methods fail to estimate the peak of the original curve. Also twice, the interpolation methods significantly overestimate the wind speeds. Neither the linear nor the polynomial approaches manage to capture the fluctuations in the original curve accurately.

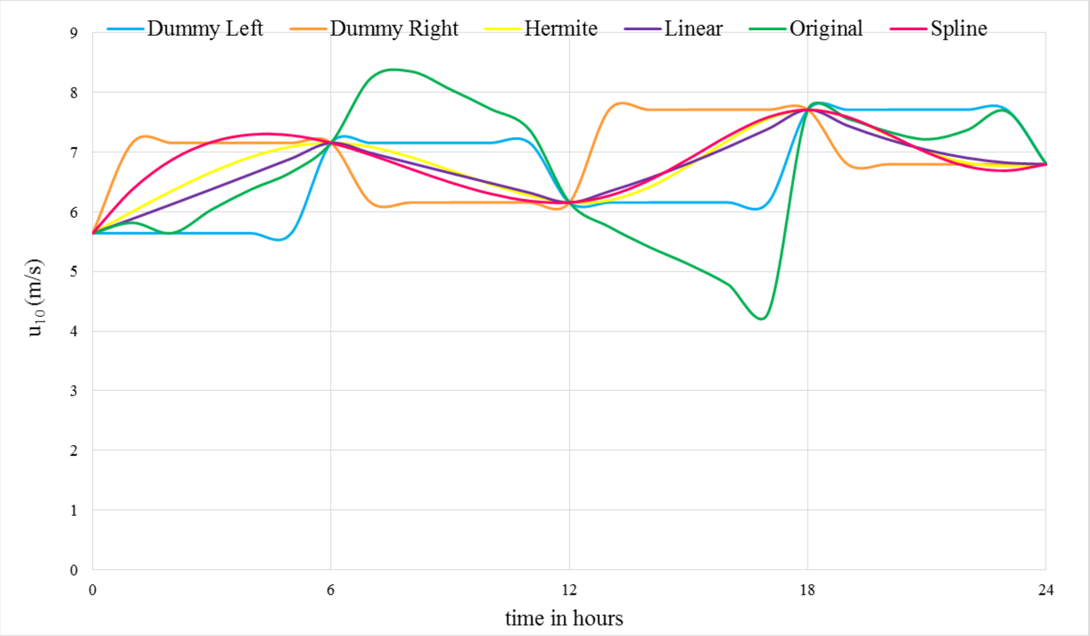


Figure 4.1. Comparison of different interpolation approaches used to increase the temporal resolution of a wind speed dataset from 6-hours to hourly

For the 24 hours represented in Figure 4.1, it is noteworthy that the closest method to estimate the peak points of the original curve is the Dummy Right method whereas the Dummy Left method produces the curve farthest away from the original curve. Also, it is noteworthy that the Dummy Right method has a tendency to estimate the peak values before the original curve reaches the peak wind speed.

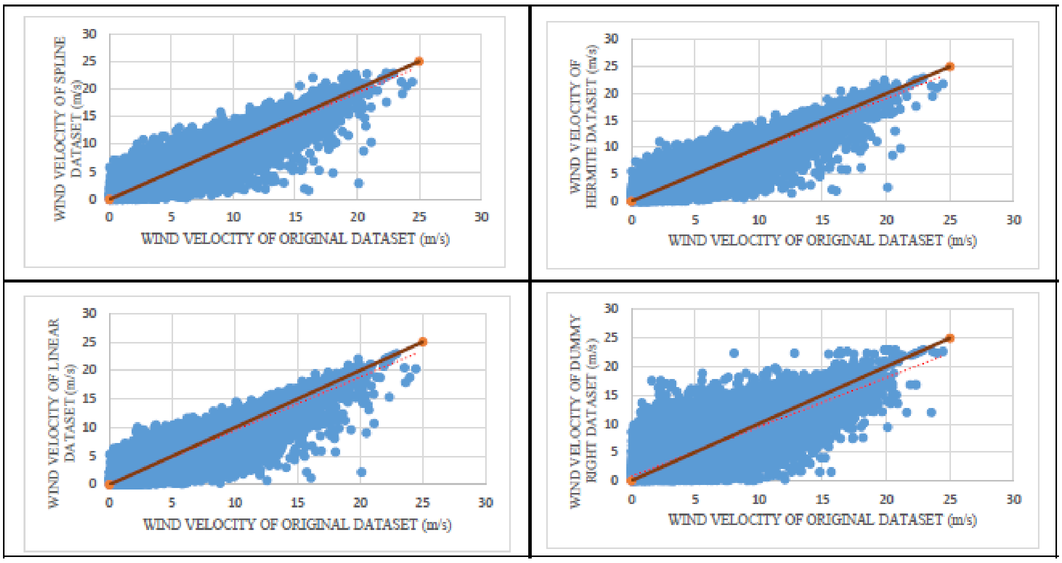
Güler et al. (2016a, 2016b) had used three main statistical parameters for discussion of their results but more statistical parameters had also been calculated as part of their research. (G. Güler, personal communication, 2016). The main selected parameters were Prediction Skill (PS), Coefficient of Variation Root Mean Square Error (CVRMSE) and Mean Absolute Error (MAE). These parameters were preferred because they are universally accepted and considered to be reliable for analyzing large time series expressing; thus making them the prior parameters for this research also. In addition to these parameters, the Variance Ratio is included as a part of this research. Variance Ratio has been deemed necessary as a numerical representation of the difference of scatter of the interpolated datasets.

Wind datasets obtained from Güler et al. (2016a, 2016b) is used to plot wind speed scatter diagrams between the original CFSR values and wind speed for each of the previously determined interpolation methods. Four scatter diagrams have been prepared for all of the selected 25 points within the Black Sea. An example for Point SW_7 is given in Figure 4.2 below. For each scatter graph, a trend line (indicated with orange colored dashed line) is drawn with a reference line of equality (1:1 line). Trend lines falling below the line of equality indicates an underestimation of wind speeds and trend lines above the line of equality indicates an overestimation of wind speeds.

Even though statistical analysis is available in order to compare the interpolation methods numerically with each other; graphical notations also are introduced. These notations are important for indicating the scatter of the data for each of the inspected interpolation method with respect to the original data visually. Also, Scatter Index (SI) is computed for each interpolation method with respect to the original data in addition to the available statistical parameters. SI has been added in order to provide a numerical indication of the established scatters. It can be observed from the graphs that as the SI value increases, the scatter of the wind speed values also increases.

A wind climate summary figure has been prepared for each of the selected 25 points. The wind climate figures are presented in Appendix A.

POINT SW_7 - N: 41.99° E: 32.19°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8915	0.0138	0.1618	0.2074	0.9989	0.1772
2	Hermite	0.8912	0.0459	0.1634	0.2081	0.9805	0.1790
3	Linear	0.8854	0.0899	0.1719	0.2132	0.9641	0.1883
9	D. Right	0.6688	-0.0133	0.2824	0.3927	1.0006	0.3094

*Figure 4.2.*Scatter diagrams for the wind velocity of the original data and the generated datasets using different interpolation methods. Statistical analysis parameters for the respective point is also given underneath the graphs

Prediction Skill, **MAE**, **CVRMSE**, **Variance Ratio**, and **SI** parameters provide consistent results for the selected 25 points within the Black Sea. Ranking of the performances of the interpolation methods according to **Normalized Bias**, however, generally displays significant differences compared to the other statistical parameters. For example, out of all interpolation methods, Dummy Right, which is generally deemed as more unreliable interpolation method compared to the others, has the lowest normalized bias values.

In fact ranking of performances according to the normalized bias always follows the same order for all of the selected 25 points within the Black Sea. The order is listed from the smallest absolute value to the largest as the following:

- Dummy Right/Left
- Spline
- Hermite
- Linear

This constant ranking for the normalized bias indicates that the statistical parameter evaluates the reliability of the mathematical approach independently from the wind speed data or location. Also, it is observed that with a few exceptions, normalized bias value for each interpolation method is positive; expressing a general pattern of overestimation of the generated wind speed datasets compared to the CFSR dataset. Even though the bias pattern is positive, it is observed from the scatter graphs that the generated datasets have a tendency to underestimate the wind speed values for higher wind speeds.

Out of the three sub-regions; it is observed that for the points selected within the Northern section, wind speed is higher compared to other sub-regions. Also, it is noted that for Northern sub-region MAE values are comparatively smaller than the other sections. A similar relationship can also be expressed for the South Eastern sub-region, in which the selected points are subjected to lower wind speeds compared to the other sub-regions, it is noted MAE values are comparatively higher than the other sections.

Previously in Table 3.2, the average statistics for all of the 522 points within the Black Sea calculated by Güler et al. (2016a, 2016b) had been given. In Table 4.1 the average wind statistics for the selected 25 points for this study are given. Comparing the results, it has been seen that the average MAE for the Black Sea which had been 19% for the best performing interpolation method and 36% for the worst performing interpolation method, increases slightly for the selected 25 points to 22% and 40% respectively. It also has been noted that the overall best-performing interpolation method shifts from Hermite to the Spline interpolation method for the selected 25 points, even though the difference between the average MAE's for the two interpolation methods is very insignificant.

Table 4.1. *Wind Analysis Statistics for the Selected 25 Points in the Black Sea*

	Prediction Skill	**Normalized Bias**	**CVRMSE**	**Mean Absolute Error**	**Variance Ratio**
HERMITE	0.8718	0.0747	0.1753	0.2163	0.9812
SPLINE	0.8709	0.0391	0.1733	0.2153	1.0022
LINEAR	0.8681	0.1208	0.1836	0.2206	0.9620
DUMMY RIGHT	0.6206	0.0119	0.2967	0.3990	1.0077

Wind climate analysis will be further discussed along with the wave analysis results.

4.3. Long Term Wave Analysis Using W61

Each one of the best, second best, third best and the worst interpolation methods determined for the selected 25 points have been analyzed using W61 wave model. Wave heights and wave periods for 1 hour, 10 hours, 50 hours and 100 hours have been computed for each one of them. Wave characteristics corresponding to cumulative exceedance probability of 10 hours/year (H_{10}) is a design parameter used widely in coastal engineering applications. Therefore, all the results of long term wave statistics will be discussed based on H_{10}.

For wave analysis, mean absolute error is used as the main statistical parameter in addition to CVRMSE, normalized bias, prediction skill, variance ratio and scatter index. The quality of interpolation methods performance is deemed higher if the MAE and the CVRMSE are lower. For the 10-hour mean wave height (H_{10}) values obtained, relative absolute error is selected as the main statistical parameter. Even though it is generally required to use same parameters while performing statistical comparisons, H_{10} values are not in time-series format; so it is not possible to use mean absolute error, as a statistical parameter for long term analysis. All of the following discussions are conducted while taking into consideration that; the main comparing parameters are different for wind and wave analyses.

For each of the selected 25 points through the Black Sea, a summary table consisting wave heights, wave periods and relative wave height errors are prepared. Radar graphs; showing the directional variations of H_{10} for the original wave and the generated waves have also been prepared. These summary tables are given in Appendix A for all of the 25 points.

An exemplary long term wave analysis is given in Table 5.4 for Point SE_1. In the table, the interpolation methods are listed according to their wind analysis performances. For Point SE_1, it can be observed from Table 4.2 that Spline, Hermite and Linear interpolation methods underestimate the wave heights, whereas the Dummy Right interpolation method overestimates it. Also for H_{10}, the Hermite interpolation method outperforms the other methods for wave analysis instead of the Spline interpolation method which was the better performing method for wind analysis.

Table 4.2. *Long Term Wave Analysis for Point SE_1*

LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.49	10.13	4.89	8.79	3.77	7.72	3.29	7.21	-	-	-	-
1-) Spline	6.24	9.92	4.73	8.64	3.68	7.62	3.23	7.14	-3.92	-3.19	-2.32	-1.76
2-) Hermite	6.44	10.08	4.81	8.72	3.71	7.65	3.23	7.14	-0.77	-1.51	-1.69	-1.80
3-) Linear	6.11	9.83	4.63	8.56	3.60	7.55	3.16	7.07	-5.85	-5.19	-4.40	-3.89
9-) Dummy Right	7.15	10.44	5.29	8.98	3.99	7.80	3.43	7.24	10.13	8.21	5.90	4.42

The magnitude of errors computed for the wave analysis are very important during the design stage. In Table 4.3(a) the average relative absolute errors calculated for the Black Sea region is presented. It has been concluded that for the investigated points, Hermite interpolation method has the minimum overall error with 2.33%, the close second is the Spline interpolation method with 2.63% average relative error. The linear interpolation method is the 3rd best interpolation method according to the overall relative errors calculated for all 25 points and the Dummy Right interpolation method results in the highest overall relative error with 5.72%. Table 4.3(b), Table 4.3(c) and Table 4.3(d) also confirm that the similar rankings are valid for the South East, South West, and North sub-regions. Additionally, in Table 4.3, the minimum and maximum errors obtained for each interpolation method are presented. It is observed that the Dummy Right method, which is the worst overall performing interpolation method, is also capable of estimating the significant wave height with very low margins of error for at least 2 points.

Spline and Hermite interpolation methods had been named as the best performing methods for wind analysis. If the design of coastal structures in the Black Sea were to be based upon wave heights calculated using Spline or Hermite interpolation methods, the expected average wave height error is within the admissible range (up to 2.63%) but it should also be noted that location-based maximum error for these two interpolation methods is up to 8.36%.

This differences between the maximum, minimum and average absolute relative errors make it compulsory to investigate the selected 25 points separately.

Table 4.3. *(a) Maximum, average and minimum H10 wave height absolute relative errors of the selected 25 points. (b) Maximum, average and minimum H10 wave height absolute relative errors of the selected points in the South West sub-region of the Black Sea. (c) Maximum, average and minimum H10 wave height absolute relative errors of the selected points in the South East sub-region of the Black Sea. (d) Maximum, average and minimum H10 wave height absolute relative errors of the selected points in the North sub-region of the Black Sea.*

(a)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	5.55	2.33	0.01
SPLINE	8.36	2.63	0.04
LINEAR	8.40	3.74	0.02
DUMMY RIGHT	15.50	5.72	0.32
DUMMY LEFT (ONLY 2 POINTS)	7.80	7.15	6.50

(b)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	4.70	2.15	0.31
SPLINE	6.72	2.92	0.10
LINEAR	7.83	3.53	0.94
DUMMY RIGHT	9.32	4.34	0.76

(c)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	4.88	1.92	0.01
SPLINE	6.35	2.13	0.04
LINEAR	5.94	3.46	0.70
DUMMY RIGHT	13.01	6.06	1.69

(d)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	5.55	2.98	0.01
SPLINE	8.36	2.92	0.30
LINEAR	8.40	4.28	0.02
DUMMY RIGHT	15.50	6.60	0.32

Bar diagrams have been prepared to discuss each point separately with respect to the sub-regions they are located in. For every point, the bars representing the relative absolute errors have been set in order according to their wind analysis rankings from the best interpolation method to the worst.

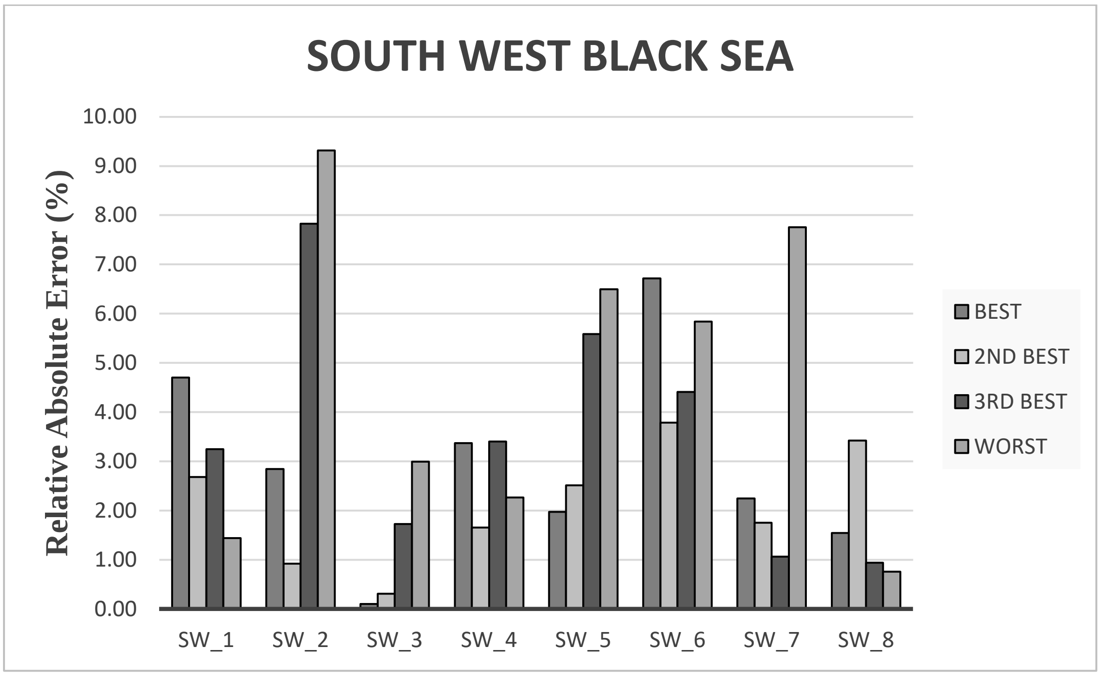


Figure 4.3. Relative Absolute Error Comparison Diagram of H10 wave heights at South West sub-region of the Black Sea for best, second best, third best and worst interpolation methods according to the wind analysis.

In the **South West** sub-region, only Point SW_3 and Point SW_5 follows the same ranking pattern as its wind analysis counterpart. Also, even though it is the best interpolation method for SW_1 and SW_8, relative absolute error for Dummy Right is generally much higher than other highest errors (Figure 4.3).

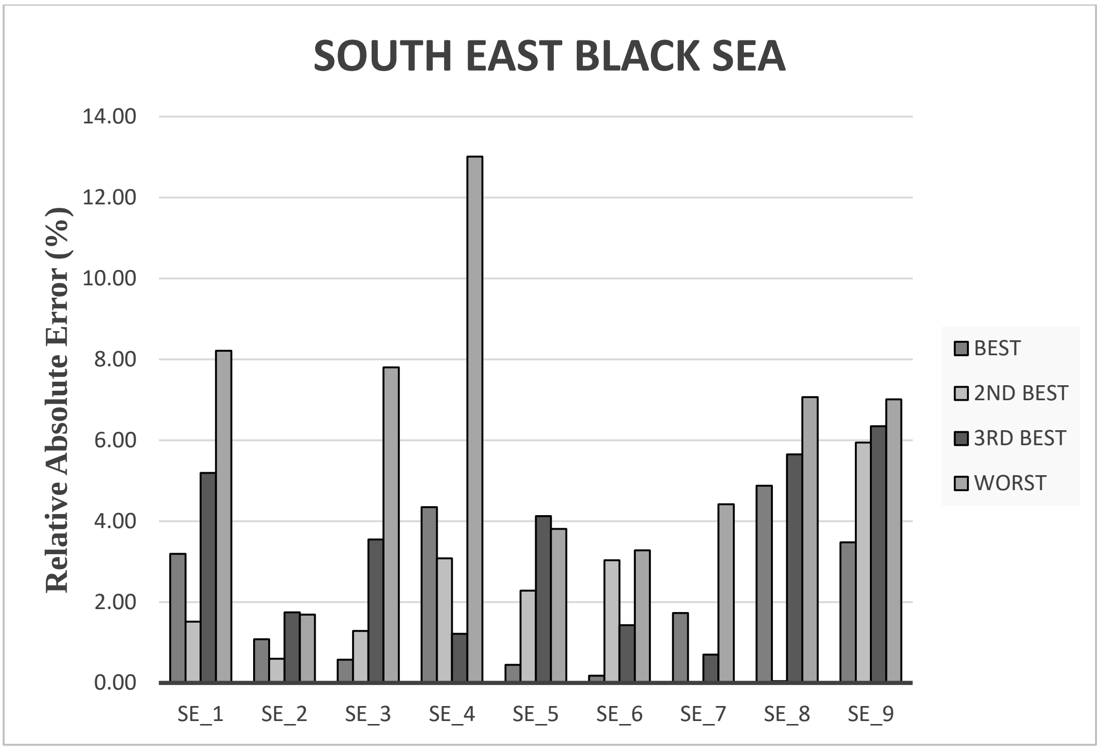


Figure 4.4. Relative Absolute Error Comparison Diagram of H10 wave heights at South East sub-region of the Black Sea for best, second best, third best and worst interpolation methods according to the wind analysis.

In the **South East** sub-region, only Point SE_3 and SE_9 follow the same ranking pattern as its wind analysis counterpart. For points SE_7 and SE_8, the errors for the second best interpolation method (which are Hermite and Spline respectively) are so low that the interpolated analysis results in nearly the same wave heights. Also, Dummy Right is the worst interpolation method for all points except for SE_2 and SE_5 (Figure 4.4).

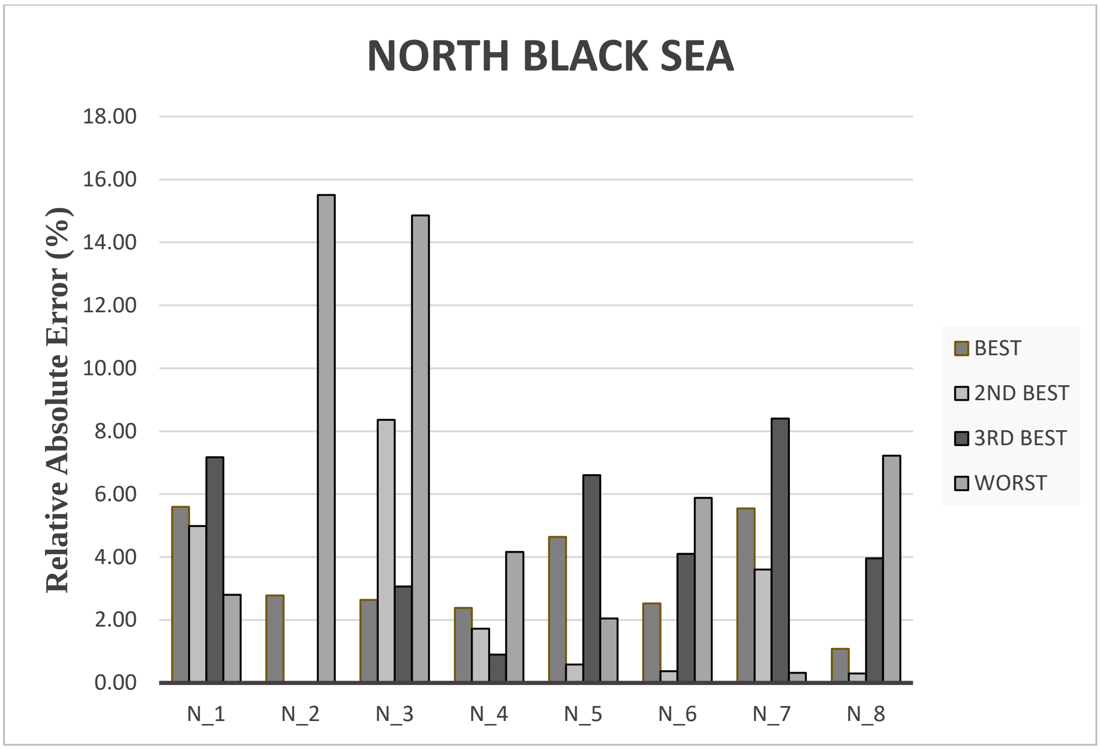


Figure 4.5. Relative Absolute Error Comparison Diagram of H10 wave heights at North sub-region of the Black Sea for best, second best, third best and worst interpolation methods according to the wind analysis.

In the **North** sub-region, none of the 9 points exhibits the same ranking pattern as its wind analysis counterpart. For the Point N_2, the error for the second and third best interpolation methods (Hermite and Linear respectively), is so low that the generated analysis results are nearly the same as original wave heights. Also, even though it is the best interpolation method for N_1 and N_7, relative absolute errors for Dummy Right are generally much higher than other highest errors (Figure 4.5).

Even though the error calculations indicate a consistency for the overall results; investigating the results for each of the 25 points separately, it is observed that the performances of the interpolation methods vary throughout the Black Sea. In Table 4.4 the interpolation methods with the lowest relative error for each of the investigated 25 points are presented. The table has been conducted in two parts. In the first part the best interpolation method and computed MAE from the wind analysis with the corresponding relative absolute error for that interpolation method from the wave analysis is given. In the second part, the best interpolation method and the computed relative absolute error with the corresponding MAE for that interpolation method from the wind analysis are given. From Table 4.4 it is clearly seen that the best interpolation method varies for wave analysis throughout the Black Sea. Also, the table shows that the best interpolation method for the wind analysis is not the best method for wave analysis for most of the investigated points.

For instance, for Point N_7, if the long term wave design were to be based on Hermite interpolation method since it performs the best for wind analysis, it would have resulted with 5.55% error. Whereas the Dummy Right interpolation method, which would not have been selected based on the wind analysis due to high MAE, performs the best with 0.32% relative absolute error.

Table 4.4. *Best interpolation methods of wind and long term wave analysis, the mean absolute error and relative error for the analysis respectively and corresponding analysis error.*

	WIND (ALL DATA)			WAVE (LONG TERM WAVE ANALYSIS)			
	BEST INTERPOLATION METHOD	MEAN ABSOLUTE ERROR (%)	CORRESPONDING WAVE H_{10} ABSOLUTE ERROR (%)	BEST INTERPOLATION METHOD	H_{10} ABSOLUTE ERROR (%)	CORRESPONDING WIND MEAN ABSOLUTE ERROR (%)	WIND RANK
SW_1	HERMITE	15.9983	4.7018	D. RIGHT	1.4393	34.1296	4
SW_2	SPLINE	16.3068	2.8445	HERMITE	0.9186	16.4914	2
SW_3	SPLINE	18.2229	0.1042	SPLINE	-	-	1
SW_4	SPLINE	21.3308	3.3683	HERMITE	1.6576	21.8717	2
SW_5	SPLINE	22.3901	1.9741	SPLINE	-	-	1
SW_6	SPLINE	22.0682	6.7172	HERMITE	3.7825	22.4654	2
SW_7	SPLINE	20.7355	2.2435	LINEAR	1.0644	21.3159	3
SW_8	HERMITE	18.5931	1.5432	D. RIGHT	0.7562	36.2547	4
SE_1	SPLINE	21.2653	3.1925	HERMITE	1.5140	21.3187	2
SE_2	SPLINE	20.9543	1.0781	HERMITE	0.5940	21.1389	2
SE_3	SPLINE	22.6502	0.5722	SPLINE	-	-	1
SE_4	SPLINE	27.8294	4.3451	LINEAR	1.2145	28.5220	3
SE_5	SPLINE	30.6640	0.4465	SPLINE	-	-	1
SE_6	HERMITE	28.0656	0.1799	HERMITE	-	-	1
SE_7	SPLINE	33.9197	1.7309	HERMITE	0.0074	34.0238	2
SE_8	HERMITE	30.0172	4.8781	SPLINE	0.0430	30.2004	2
SE_9	HERMITE	29.8187	3.4776	HERMITE	-	-	1
N_1	SPLINE	14.8119	5.5977	D. RIGHT	2.7959	32.4444	4
N_2	SPLINE	14.6086	2.7832	HERMITE	0.0082	14.7828	2
N_3	HERMITE	15.0151	2.6406	HERMITE	-	-	1
N_4	HERMITE	17.6926	2.3856	LINEAR	0.9025	17.8916	3
N_5	HERMITE	18.1344	4.6453	SPLINE	0.5837	18.1793	2
N_6	HERMITE	16.4230	2.5253	SPLINE	0.3759	16.3777	2
N_7	HERMITE	16.7847	5.5460	D. RIGHT	0.3218	33.3306	4
N_8	HERMITE	22.5595	1.0815	SPLINE	0.2952	22.6099	2

In Figure 4.6, computed errors of the best interpolation method for the wind and wave analyses have been plotted with the errors from the corresponding analysis for the same interpolation method. The pointers with blue color represent the MAE of the wind analysis plotted against the relative absolute error of wave analysis for the best interpolation method according to wind analysis. Secondly, the pointers with orange color represent the MAE of the wind analysis plotted against the relative absolute error of wave analysis for the best interpolation method according to wave analysis. For 15 points out of the investigated 25, the best performing interpolation method would not have been selected for wave analysis due to poor performance according to the wind analysis.

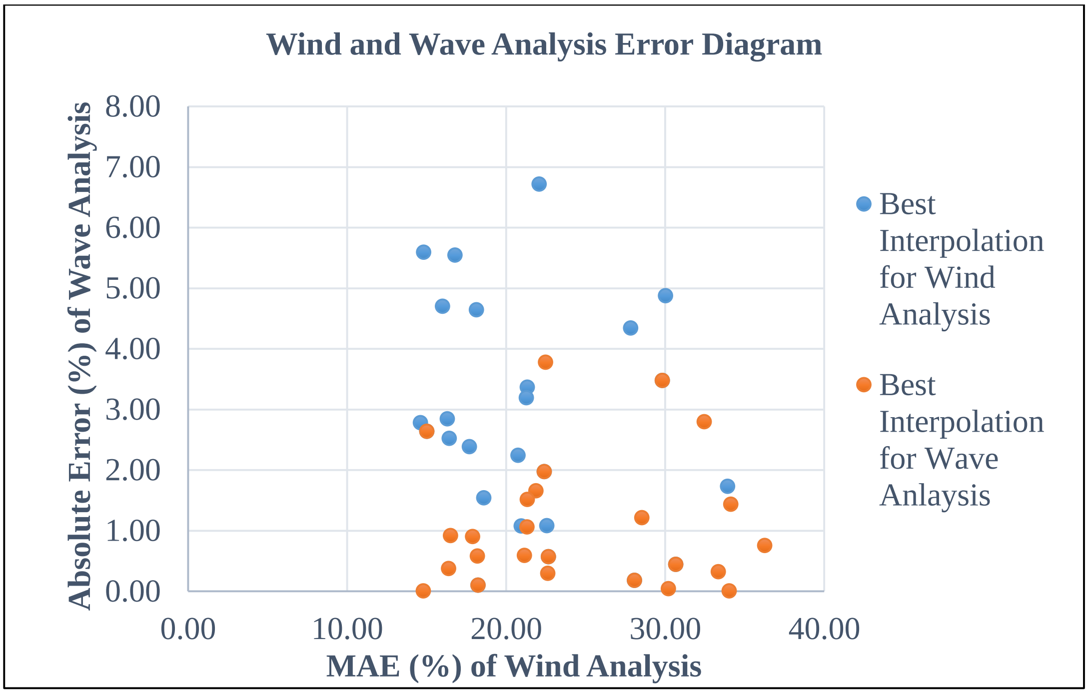


Figure 4.6. Absolute Error (%) of Wave Analysis vs MAE (%) of Wind Analysis

One of the main aims of this study had been defined as controlling the compatibility of the performances of different interpolation methods for wind analysis and wave analysis. The complete rankings of performances for both wind analysis and wave analysis are given in Table 4.5 where each interpolation method is represented with a different color.

Table 4.5. *Comparison of the performance rankings of generated wind analysis and generated long term wave analysis with respect to the original datasets.*

POINT	REGION	WIND BEST	WIND 2ND BEST	WIND 3RD BEST	WIND WORST	WAVE BEST	WAVE 2ND BEST	WAVE 3RD BEST	WAVE WORST
SW_1	SOUTH WEST REGION OF BLACK SEA	HERMITE	SPLINE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	SPLINE	LINEAR	HERMITE
SW_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	SPLINE	LINEAR	DUMMY RIGHT
SW_3		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SW_4		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	DUMMY RIGHT	SPLINE	LINEAR
SW_5		SPLINE	HERMITE	LINEAR	DUMMY LEFT	SPLINE	HERMITE	LINEAR	DUMMY LEFT
SW_6		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	DUMMY RIGHT	SPLINE
SW_7		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	SPLINE	DUMMY RIGHT
SW_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	LINEAR	HERMITE	SPLINE
SE_1	SOUTH EAST REGION OF BLACK SEA	SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	SPLINE	LINEAR	DUMMY RIGHT
SE_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	SPLINE	DUMMY RIGHT	LINEAR
SE_3		SPLINE	HERMITE	LINEAR	DUMMY LEFT	SPLINE	HERMITE	LINEAR	DUMMY LEFT
SE_4		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	SPLINE	DUMMY RIGHT
SE_5		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	DUMMY RIGHT	LINEAR
SE_6		HERMITE	LINEAR	SPLINE	DUMMY RIGHT	HERMITE	SPLINE	LINEAR	DUMMY RIGHT
SE_7		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	SPLINE	DUMMY RIGHT
SE_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SE_9		HERMITE	LINEAR	SPLINE	DUMMY RIGHT	HERMITE	LINEAR	SPLINE	DUMMY RIGHT
N_1	NORTH REGION OF BLACK SEA	SPLINE	HERMITE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	HERMITE	SPLINE	LINEAR
N_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	SPLINE	DUMMY RIGHT
N_3		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	SPLINE	DUMMY RIGHT
N_4		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	LINEAR	SPLINE	HERMITE	DUMMY RIGHT
N_5		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	SPLINE	DUMMY RIGHT	HERMITE	LINEAR
N_6		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	LINEAR	DUMMY RIGHT
N_7		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	SPLINE	HERMITE	LINEAR
N_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	LINEAR	DUMMY RIGHT

Out of the selected 25 points, only 4 points have the same interpolation method rankings for both wind analysis and H_{10} analysis. In addition to these 4 points, another 3 points have the same best interpolation method for wind analysis and H_{10} but show differences between the rankings of other interpolation methods.

Whereas 4 points have the same best interpolation method for both wind analysis and long term wave analysis. For the rest of the 25 selected points, the interpolation method with the smallest absolute relative H_{10} error, is the second best interpolation method for the wind analysis for 44% of the points, the third best method for 12% of the points and with the worst for 16% of the points.

In total 75 analyses have been performed for Spline, Hermite, and Linear interpolation methods. Out of these analyses, only 26 of them result in higher wave heights compared to the wave heights obtained from the original wind dataset. Thus it can be said that for Spline, Hermite or Linear interpolation methods, almost 1/3 of the analysis results in overestimation. On the other hand, out of the 25 analysis performed for Dummy Right and Left interpolation methods, 22 analysis result in higher wave height values compared to the wave heights computed using original wind dataset.

If a wave analysis were to be performed using a wind dataset using the best interpolation method that was previously determined for each one of these selected 25 points, for 15 of these points; the resulting H_{10} wave heights would have been smaller than the ones that would have been computed using the original wind dataset.

Main wave propagation direction is also a very important long term wave analysis parameter. In the scope of this research, a wave direction radar graph for each of the selected points have been prepared. Out of the 25 points, at 8 of them, main propagation direction for the interpolation methods differ from the one determined from the original dataset. In Figure 4.7, the main direction of the wave H_{10} for Point N_2 calculated from the original wind dataset and the interpolated dataset using Spline is North East. Whereas wave direction of the H_{10} calculated from the interpolated dataset with Hermite is South and from the interpolated dataset Dummy Right is South-South-West direction.

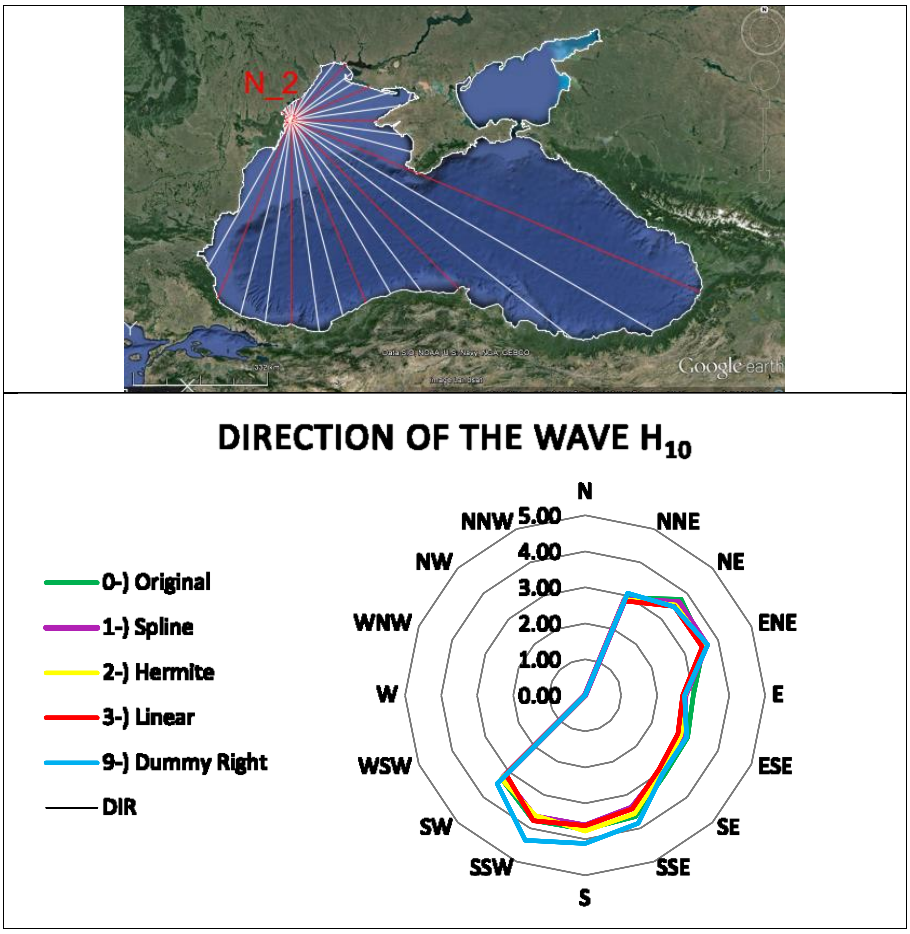


Figure 4.7. Direction variation graph for H10 of Point N_2.

In general, no apparent relationship between the ranking of the interpolation methods for wind analysis and the ranking of the interpolation methods for long term wave analysis is found, for the selected 25 points in the Black Sea. In addition to that, none of the interpolation methods that were investigated in this research can be named as the best interpolation method for long term wave analysis at the Black Sea, considering the investigated 25 points. Even though the best interpolation method for long term wave analysis for the selected points differs throughout the Black Sea and the previously determined sub-regions; Hermite method has the overall lowest mean absolute error, closely followed by Spline interpolation method (Table 4.5).

Also, it is noteworthy that, while the methods with lower mean absolute errors have a tendency to underestimate the H_{10} values; Dummy Right interpolation method, which have the highest mean absolute error, have a tendency to overestimate the computed H_{10} values.

Moreover, it is observed that the main wave propagation direction may show differences when using an interpolated dataset.

4.4. Extreme Wave Analysis Using W61

As it had been done for long term wave analysis, each one of the best, second best, third best and the worst interpolation methods determined by Güler et al. (2016a) for all selected 25 points have been analyzed using W61 wave model. Wave heights and wave periods for 50 years and 100 years have been computed for each one of them. Generally, for extreme wave analysis applications, 100 years analysis parameters are preferred; thus, further on all of the results will be discussed according to 100 years analysis.

For each of the selected 25 points through the Black Sea, a summary table consisting of wave heights, wave periods and relative absolute wave height errors have been prepared. These summary tables are given in Appendix A for all of the 25 points.

An exemplary extreme wave analysis is given in Table 4.6 for Point SE_1. As it had been for long term wave analysis, the interpolation methods are listed according to their wind analysis performances. Previously for wind analysis, Spline interpolation method performed better than the other interpolation methods but for wave analysis, it can be seen from Table 4.6 that Hermite interpolation method performs the best for H_{100} design wave height.

Table 4.6. *Extreme Wave Analysis for Point SE_1.*

EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.56	10.43	7.90	10.66	-	-
1-) Spline	7.61	10.39	7.97	10.64	0.58	0.79
2-) Hermite	7.55	10.30	7.92	10.55	-0.14	0.16
3-) Linear	7.40	10.44	7.76	10.69	-2.13	-1.87
9-) Dummy Right	7.80	11.73	8.17	12.01	3.12	3.41

Considering that even a 5% change in the selected design wave height, may alter the weight of the selected stones for a breakwater design up to 20% percent, the magnitude of errors are very important for extreme wave analysis. In Table 4.7(a), the average relative absolute errors calculated for extreme wave analysis in the Black Sea region are presented. It has been concluded that for the investigated points, Hermite interpolation method has the minimum overall error with 3.10%, the close second method is the Spline interpolation method with 3.37% average relative error. The linear interpolation method is the 3rd best interpolation method according to the overall relative errors calculated for all 25 points and the Dummy Right interpolation method results in the highest overall relative error with 4.41%.

On the other hand, the overall rankings for the sub-regions show differences (Table 4.7(b), Table 4.7(c), and Table 4.7(d)). For instance, for the South West sub-region, the overall average relative error for the Linear interpolation is smaller than the Hermite and Spline interpolation methods.

In Table 4.7, also the minimum and maximum errors obtained for each interpolation method are presented. It is observed that the Dummy Right method, which is the worst overall performing interpolation method, is also capable of estimating the significant wave height with very low margins of error for at least 1 point. Additionally, the Linear interpolation method has a considerably smaller maximum error than Spline and Hermite interpolation methods and Spline interpolation method, which overall performs the 2nd best, have the highest maximum error among all the investigated methods with 14.36%.

The differences between the maximum, minimum and average absolute relative errors male it compulsory to investigate the selected 25 points separately.

Table 4.7. *(a) Maximum, average and minimum H100 wave height absolute relative errors of the selected 25 points. (b) Maximum, average and minimum H100 wave height absolute relative errors of the selected points in the South West sub-region of the Black Sea. (c) Maximum, average and minimum H100 wave height absolute relative errors of the selected points in the South East sub-region of the Black Sea. (d) Maximum, average and minimum H100 wave height absolute relative errors of the selected points in the North sub-region of the Black Sea.*

(a)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	11.19	3.10	0.14
SPLINE	14.36	3.37	0.44
LINEAR	8.49	3.38	0.26
DUMMY RIGHT	12.69	4.41	0.24
DUMMY LEFT (ONLY 2 POINTS)	3.01	2.91	2.82

(b)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	6.82	2.30	0.14
SPLINE	5.24	2.16	0.90
LINEAR	3.44	1.56	0.37
DUMMY RIGHT	4.57	2.61	1.20

(c)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	11.19	4.05	0.16
SPLINE	14.36	4.38	0.47
LINEAR	8.49	5.15	0.26
DUMMY RIGHT	12.69	5.44	0.24

(d)	MAX ERR (%)	AVE ERR (%)	MIN ERR (%)
HERMITE	7.75	2.82	0.60
SPLINE	6.94	3.44	0.44
LINEAR	8.20	3.28	0.68
DUMMY RIGHT	8.18	4.96	1.34

Bar diagrams have been prepared to discuss the errors with respect to the sub-regions they are located in. For every point, the bars representing the relative errors have been set in order according to their wind analysis rankings from the best interpolation method to the worst.

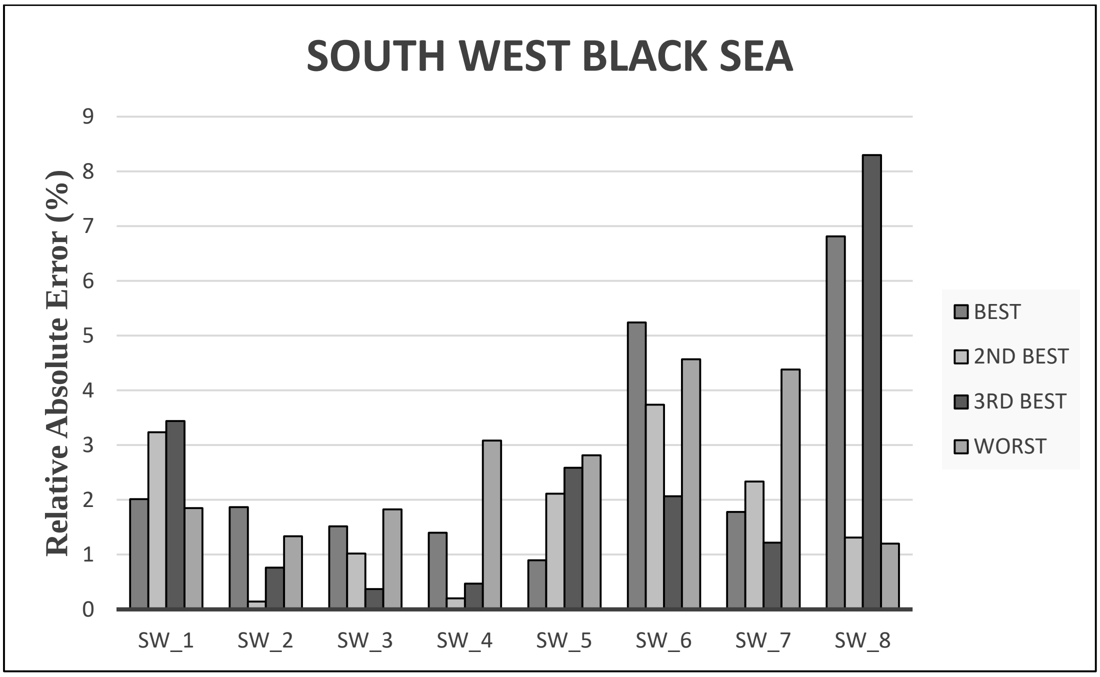


Figure 4.8. Relative Absolute Error Comparison Diagram of H100 wave heights at South West sub-region of the Black Sea for best, second best, third best and worst interpolation methods according to the wind analysis.

In the **South West** sub-region, only Point SW_5 follows the same ranking pattern as its wind analysis counterpart. In fact, SW_5 is the only point that has the same performance ranking for wind, long term wave, and extreme wave analyses (Figure 4.8).

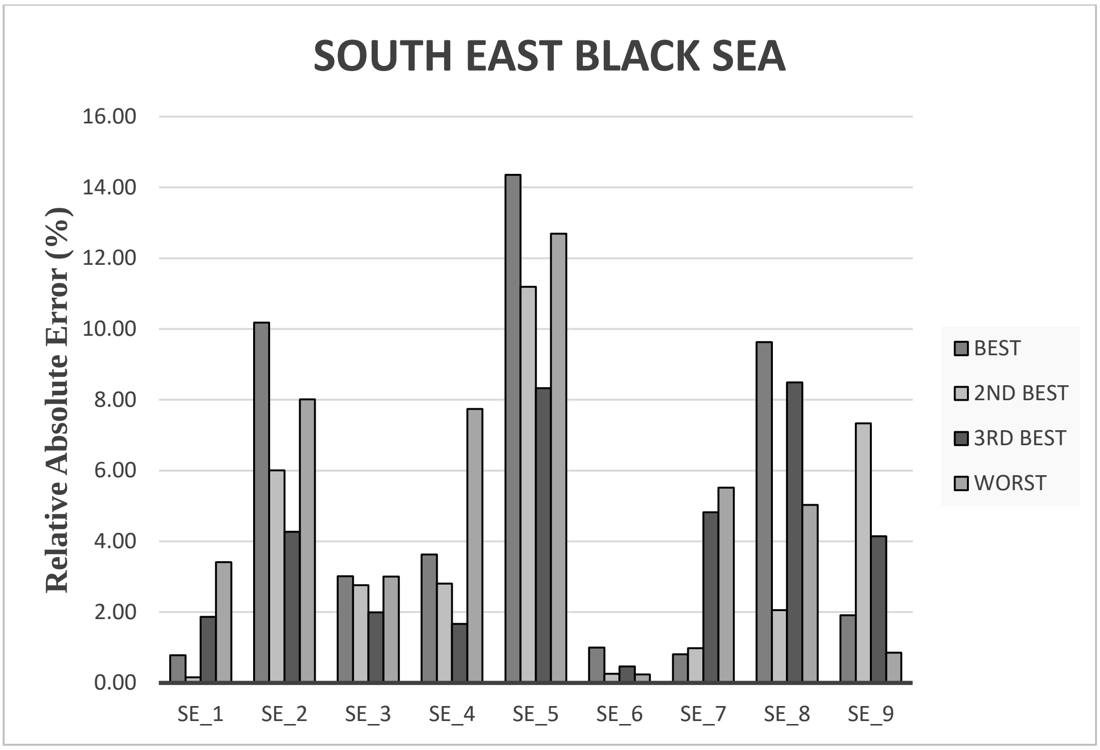


Figure 4.9. Relative Absolute Error Comparison Diagram of H100 wave heights at South East sub-region of the Black Sea for best, second best, third best and worst interpolation methods according to the wind analysis.

In the **South East** sub-region, only Point SE_7 follows the same ranking pattern as its wind analysis counterpart. For points SE_1 the error of the second best interpolation method (Hermite) and for point SE_6, the error for the second and the worst best interpolation method (which are Linear and Dummy Right respectively) is so low that the interpolated analysis results in nearly the same wave heights. Also, Points SE_2 and SE_5 follow the same performance ranking for extreme wave analysis (Figure 4.9).

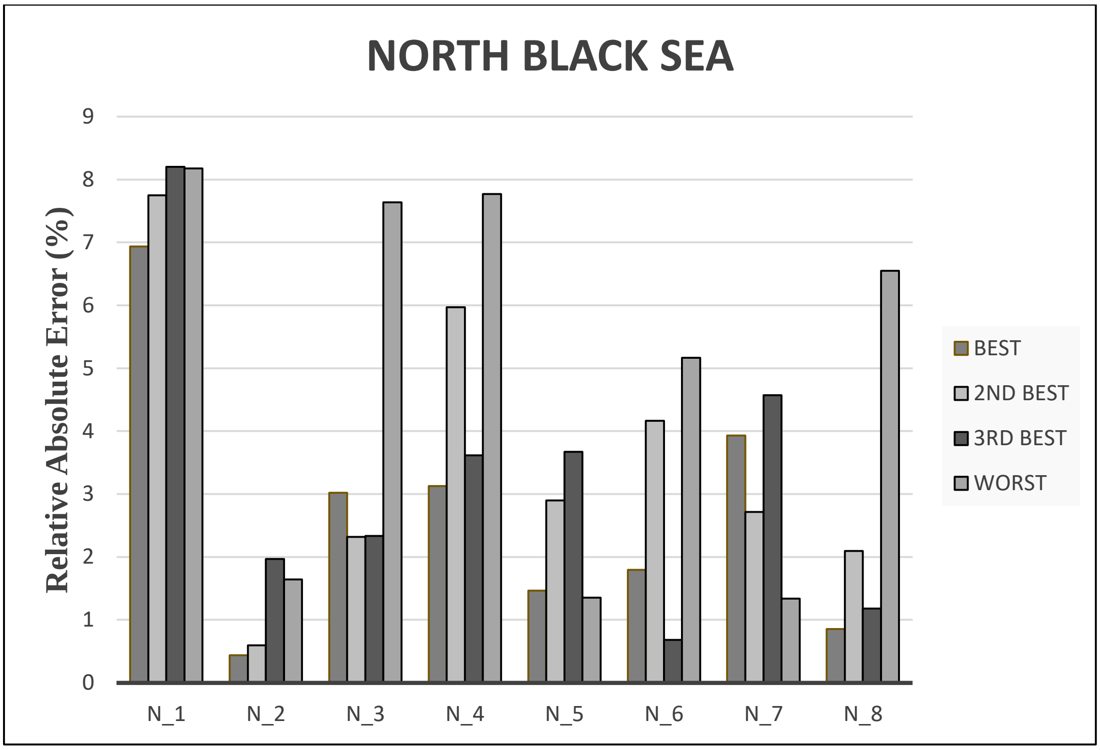


Figure 4.10. Relative Absolute Error Comparison Diagram of H100 wave heights at North sub-region of the Black Sea for best, second best, third best and worst interpolation methods according to the wind analysis.

In the **North** sub-region, none of the 9 points exhibits the same ranking pattern as its wind analysis counterpart. Points N_1 and N_2 exhibit the same performance ranking but the magnitude of errors are very different compared to each other. Points N_4 and N_8 also follow the same performance ranking order (Figure 4.10).

In Table 4.8 the interpolation methods with the lowest relative absolute error for each of the investigated points are presented. The table is conducted in two parts. In the first part the best interpolation method and computed MAE from the wind analysis with the corresponding relative absolute error for that interpolation method from extreme wave analysis is given. In the second part, the best interpolation method and the computed relative absolute error for extreme wave analysis with the corresponding MAE for that interpolation method from the wind analysis are presented. In Table 4.8

it is clearly seen that the best interpolation method varies for extreme wave analysis varies throughout the Black Sea. Also, the table shows that the best interpolation method for wind analysis is not the best method for wave analysis for most of the investigated points.

For instance, for Point SE_5, if the extreme wave design were to be based on the Spline interpolation method, since it performs the best for wind analysis, it would have resulted with 14.36% error. Whereas the Linear interpolation method, which would not have been selected based on the wind analysis due to high MAE, performs the best with 8.33% relative absolute error. However, it should also be noted that even if the linear interpolation method performs the best for Point SE_5, 8.33% possible error is still very high for extreme wave design.

Table 4.8. *Best interpolation methods of wind and extreme wave analysis, the mean absolute error and relative error for the analysis respectively and corresponding analysis error.*

	WIND (ALL DATA)			WAVE (EXTREME WAVE ANLAYSIS)			
	BEST INTERPOLATION METHOD	MEAN ABSOLUTE ERROR (%)	CORR. WAVE H_{100} ABSOLUTE ERROR	BEST INTERPOLATION METHOD	H_{100} ABSOLUTE ERROR (%)	CORR. WIND MEAN ABSOLUTE ERROR (%)	WIND RANK
SW_1	HERMITE	15.9983	2.0159	DUMMY RIGHT	1.8478	34.1296	4
SW_2	SPLINE	16.3068	1.8710	HERMITE	0.1435	16.4914	2
SW_3	SPLINE	18.2229	1.5190	LINEAR	0.3722	19.1298	3
SW_4	SPLINE	21.3308	1.3976	HERMITE	0.2010	21.8717	2
SW_5	SPLINE	22.3901	0.8951	SPLINE	-	-	1
SW_6	SPLINE	22.0682	5.2407	LINEAR	2.0698	23.3585	3
SW_7	SPLINE	20.7355	1.7779	LINEAR	1.2194	21.3159	3
SW_8	HERMITE	18.5931	6.8183	DUMMY RIGHT	1.2032	36.2547	4
SE_1	SPLINE	21.2653	0.7854	HERMITE	0.1611	21.3187	2
SE_2	SPLINE	20.9543	10.1786	LINEAR	4.2722	21.6264	3
SE_3	SPLINE	22.6502	3.0170	LINEAR	1.9902	23.6911	3
SE_4	SPLINE	27.8294	3.6264	LINEAR	1.6639	28.5220	3
SE_5	SPLINE	30.6640	14.3566	LINEAR	8.3290	31.0816	3
SE_6	HERMITE	28.0656	1.0006	DUMMY RIGHT	0.2404	49.4044	4
SE_7	SPLINE	33.9197	0.8107	SPLINE	-	-	1
SE_8	HERMITE	30.0172	9.6324	SPLINE	2.0596	30.2004	2
SE_9	HERMITE	29.8187	1.9118	DUMMY RIGHT	0.8572	48.7751	4
N_1	SPLINE	14.8119	6.9376	SPLINE	-	-	1
N_2	SPLINE	14.6086	0.4371	SPLINE	-	-	1
N_3	HERMITE	15.0151	3.0212	SPLINE	2.3176	14.9784	2
N_4	HERMITE	17.6926	3.1265	HERMITE	-	-	1
N_5	HERMITE	18.1344	1.4629	DUMMY RIGHT	1.3553	35.8216	4
N_6	HERMITE	16.4230	1.7960	LINEAR	0.6823	16.5513	3
N_7	HERMITE	16.7847	3.9300	DUMMY RIGHT	1.3395	33.3306	4
N_8	HERMITE	22.5595	0.8544	HERMITE	-	-	1

In Figure 4.11 computed errors for the best interpolation method for the extreme wave analysis and the corresponding wind analysis errors have been plotted with the errors of the best interpolation method for the wind analysis and the corresponding wave analysis errors. The pointers with blue color represent the MAE of the wind analysis plotted against the relative absolute error of extreme wave analysis for the best interpolation method according to wind analysis. Secondly, the pointers with orange color represent the MAE of the wind analysis plotted against the relative absolute error of extreme wave analysis for the best interpolation method according to wave analysis. For 19 points out of the investigated 25, the best performing interpolation method would not have been selected for wave analysis due to poor performance according to the wind analysis.

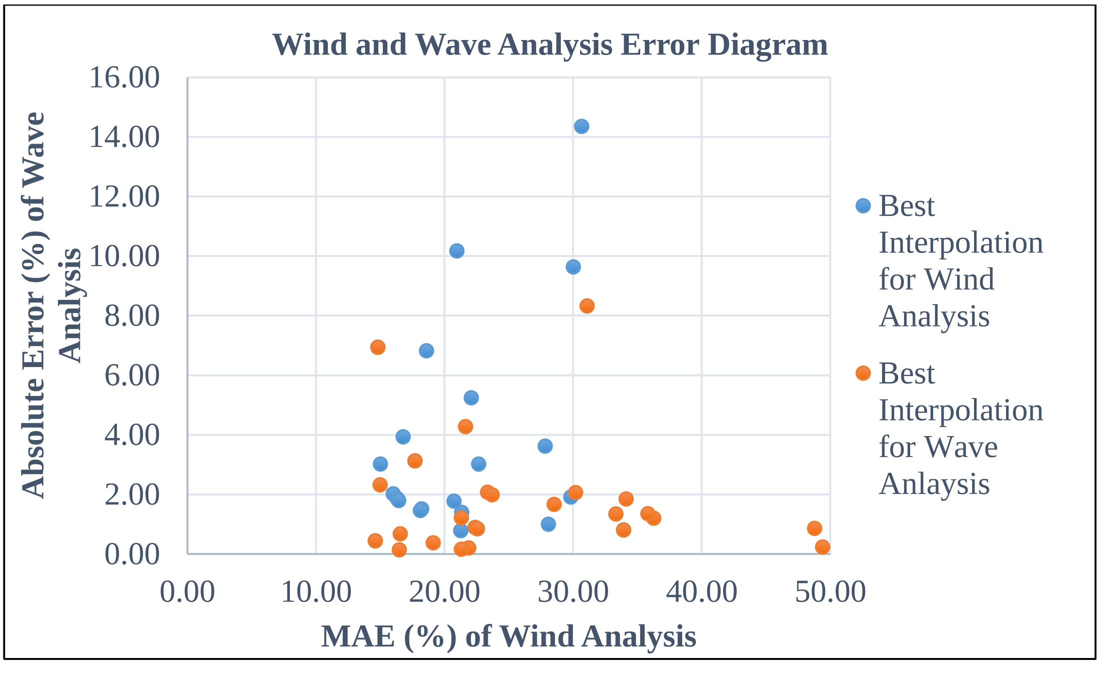


Figure 4.11. Absolute Error (%) of Extreme Wave Analysis vs MAE (%) of Wind Analysis

One of the main aims of this study had been defined as controlling the compatibility of the performances of different interpolation methods for wind analysis and wave analysis. The complete rankings of performances for both wind analysis and wave analysis are given in Table 4.9 where each interpolation method is represented with a different color.

Table 4.9. *Comparison of the performance rankings of generated wind analysis and generated extreme wave analysis with respect to the original datasets.*

POINT	REGION	WIND				WAVE			
		BEST	2ND BEST	3RD BEST	WORST	BEST	2ND BEST	3RD BEST	WORST
SW_1	SOUTH WEST REGION OF BLACK SEA	HERMITE	SPLINE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	HERMITE	SPLINE	LINEAR
SW_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	DUMMY RIGHT	SPLINE
SW_3		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	SPLINE	DUMMY RIGHT
SW_4		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	SPLINE	DUMMY RIGHT
SW_5		SPLINE	HERMITE	LINEAR	DUMMY LEFT	SPLINE	HERMITE	LINEAR	DUMMY LEFT
SW_6		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	DUMMY RIGHT	SPLINE
SW_7		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	SPLINE	HERMITE	DUMMY RIGHT
SW_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	SPLINE	HERMITE	LINEAR
SE_1	SOUTH EAST REGION OF BLACK SEA	SPLINE	HERMITE	LINEAR	DUMMY RIGHT	HERMITE	SPLINE	LINEAR	DUMMY RIGHT
SE_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	DUMMY RIGHT	SPLINE
SE_3		SPLINE	HERMITE	LINEAR	DUMMY LEFT	LINEAR	HERMITE	DUMMY LEFT	SPLINE
SE_4		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	SPLINE	DUMMY RIGHT
SE_5		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	DUMMY RIGHT	SPLINE
SE_6		HERMITE	LINEAR	SPLINE	DUMMY RIGHT	DUMMY RIGHT	LINEAR	SPLINE	HERMITE
SE_7		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	LINEAR	DUMMY RIGHT
SE_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	SPLINE	DUMMY RIGHT	LINEAR	HERMITE
SE_9		HERMITE	LINEAR	SPLINE	DUMMY RIGHT	DUMMY RIGHT	HERMITE	SPLINE	LINEAR
N_1	NORTH REGION OF BLACK SEA	SPLINE	HERMITE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	DUMMY RIGHT	LINEAR
N_2		SPLINE	HERMITE	LINEAR	DUMMY RIGHT	SPLINE	HERMITE	DUMMY RIGHT	LINEAR
N_3		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	SPLINE	LINEAR	HERMITE	DUMMY RIGHT
N_4		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	SPLINE	DUMMY RIGHT
N_5		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	HERMITE	SPLINE	LINEAR
N_6		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	LINEAR	HERMITE	SPLINE	DUMMY RIGHT
N_7		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	DUMMY RIGHT	SPLINE	HERMITE	LINEAR
N_8		HERMITE	SPLINE	LINEAR	DUMMY RIGHT	HERMITE	LINEAR	SPLINE	DUMMY RIGHT

Out of the selected 25 points, only 2 points have the same interpolation method rankings for both wind analysis and H_{100} extreme wave height computation. In addition to these 2 points, another 4 points have the same best interpolation method for wind analysis and H_{100} but show differences between the rankings of other interpolation methods.

Whereas 6 points have the same best interpolation method for both wind analysis and extreme wave analysis; for the rest of the 25 selected points, the interpolation method with the smallest absolute relative H_{100} error, is the second best interpolation method for the wind analysis for 20% of the points, third best method for 32% of the points and result in the worst for 24% of the points.

In total 75 analyses have been performed for Spline, Hermite, and Linear interpolation methods. Out of these, 32 of them result in lower wave heights compared to the wave heights obtained from the original wind dataset. Thus it can be said that for Spline, Hermite or Linear interpolation methods, more than 1/2 of the analysis results in overestimation. This is a significant improvement compared to the long term wave analysis results, in which it is estimated that only 1/3 of the analysis for these interpolation methods give higher wave height results than the original wave heights.

If a wave analysis were to be performed using the best interpolation method that was previously determined for each one of these selected 25 points, for 8 of these points; the resulting H_{100} wave heights would have been smaller than the ones that would have been computed using the original wind data. Since extreme wave analysis controls the design of coastal structures such as breakwaters; overestimation of the design wave height is preferable than the underestimation of the wave heights due to safety reasons. On the other hand, since breakwater construction is highly expensive, overestimations will increase the cost excessively.

To sum up, any apparent relationships (that can be determined using basic statistical parameters) between the ranking of performances of Hermite, Spline, Linear and Dummy Right/Left interpolation methods for wind analysis and extreme wave analysis does not exist for the selected 25 points within the Black Sea region. Also, none of the investigated interpolation methods can be recommended as the best interpolation method for all of the selected 25 points in the Black Sea region. It can be argued that the Hermite interpolation method has the overall lowest mean error of 25 points, but for some of the investigated points Hermite interpolation method also has the highest mean error (Table 4.9).

As previously stated, the discussions have been conducted for extreme events with 100 years period. The ranking of the interpolation methods does show differences between 50-year and 100-year wave analyses for most of the points.

4.5. Storm-Based Wave Analysis Using WAVEWATCH III

While the W61 wave generation model has been used for wave climate study, WAVEWATCH III wave generation model has also been preferred for obtaining storm based time series wave analysis. WAVEWATCH III has been selected for further investigation for a better understanding of the impacts of interpolation in a time series data. The individual wave heights obtained from the WAVEWATCH III analysis for three separate storm events have been used to conduct a comparison of interpolation methods.

First two storm events have been selected among the cases inspected by Kirezci (2016) for the Black Sea. Whereas the first two storm events have been investigated for individual locations, the 3rd storm event has been investigated for all the previously selected 25 points within the Black Sea region.

As it has been stated in Section 3.3.2.2, WAVEWATCH III wave generation model offers temporal interpolations within the analysis. Since the main aim of this thesis is to evaluate and compare the performances of different interpolation methods, any additional interpolations within the analyses are undesired. Due to this reason, the input wind data have been inserted in the WAVEWATCH III with hourly time steps and the output wave data have been requested also in the hourly format.

4.5.1. WAVEWATCH III for Point N_7

Point N_7 is the closest study point to Gelendzhik station where there are available wave height measurements from 11.12.2000 at 00:00:00 to 02.01.2001 at 00:00:00. The event duration is 22 days.

Using WAVEWATCH III output data, hourly time-series graphs have been prepared for wind velocity, wave height, wave period and wave direction (0° represents wave propagation from west to east and due to cyclic order of direction, the sector between 350°- 0° represents the same direction). These graphs are given in Figure 4.12. It can be seen from Figure 4.12 that the Spline and Dummy Right interpolation methods seize the peak points of the original series much better than other interpolation methods. Also, it can be observed that the Spline and Dummy Right methods have a tendency to overestimate the peak points for Point N_7.

Figure 4.12. For N_7 Time-Series graphs (a) Wind Velocity (b) Wave Height (c) Wave Period (d) Wave Direction

In addition to Figure 4.12, Figure 4.13 and Figure 4.14 have been prepared to study the peak regions of wind velocity and wave height graphs. It can be seen in Figure 4.13 and Figure 4.14 that there is a time lag between the peak points for wind velocity and wave height. The CFSR data reaches the peak velocity at hour 151 and the peak wave height obtained from the CFSR is observed at hour 152. The time lag is relatively larger for Spline method, 3 hours.

Hermite interpolation curve is the closest to the original curve compared to the other interpolation methods but fails to catch the peak wave heights. Numerical verification for this is given in Table 4.10.

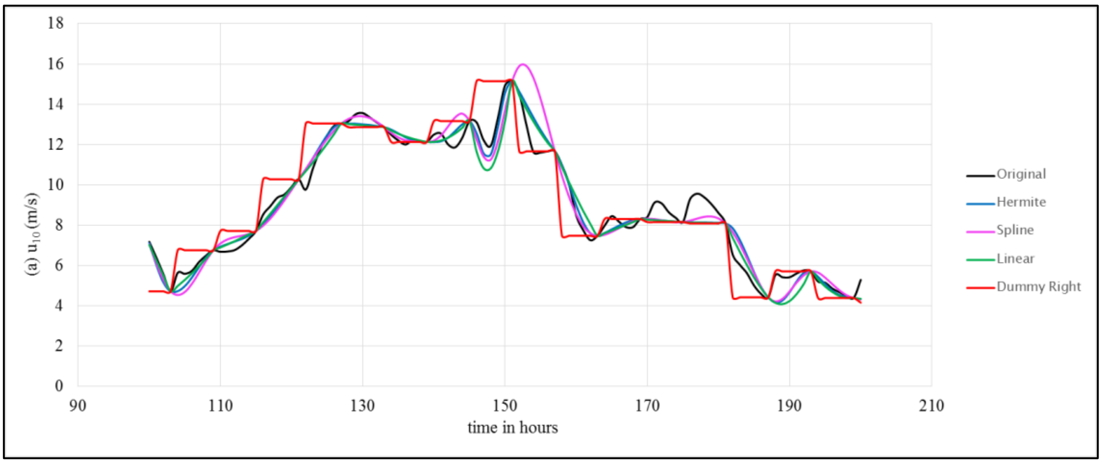


Figure 4.13. Wind Velocity time-series graph focused between 100 hours and 200 hours.

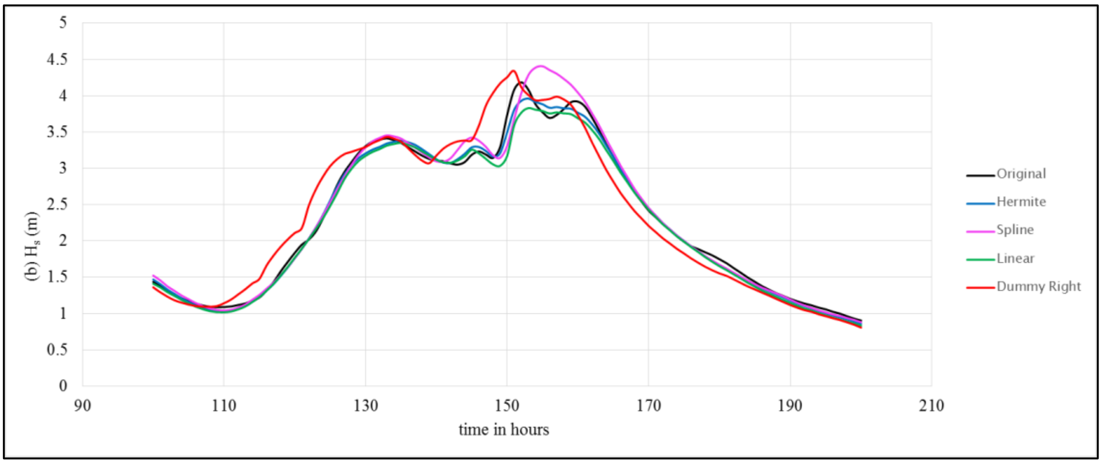


Figure 4.14. Wave Height time-series graph focused between 100 hours and 200 hours.

As had been stated earlier, Güler et al. (2016a, 2016b) had also studied extreme individual storm events. In Table 4.10, the MAE values for this individual storm events have been presented among with the MAE's for all wind data. The wave heights obtained from the WAVEWATCH III analysis have been used to compute mean average error (using all wave heights) and ER_{Hpeak} which represents the difference between the peak wave heights of the original and interpolated datasets. Also, the differences between the occurrences of the peak events have been compared.

It can be observed from Table 4.10 that the magnitude of errors are very close for WAVEWATCH III and W61. In addition to that, the performance ranking is the same at Point N_7 for both WAVEWATCH III and W61.

Table 4.10. *Statistics for Storm Event Gelendzhik_16 at Point N_7*

	Wind (Storm Event)	***WAVEWATCH III***		***W61***	***Wind (All Data)***
	MAE (%)	**MAE (%)**	**ER_{Hpeak} (%)**	**R. Error H_{100} (%)**	**MAE (%)**
Hermite	8.4423	5.0189	5.3537	3.9300	21.6298
Spline	8.9013	6.9744	5.3059	2.7142	21.5257
Linear	8.7459	5.9118	8.4847	4.5720	22.0550
Dummy Right	18.6593	9.9561	3.7285	1.3395	39.8973

4.5.2. WAVEWATCH III for Point SE_2

Point SE_2 is the closest study point to Sinop station where there are available wave height measurements from 03.11.1994 at 12:00:00 to 17.11.1994 at 00:00:00. The event duration is 14 days.

Using WAVEWATCH III output data, hourly time-series graphs have been prepared for wind velocity, wave height, wave period and wave direction (0° represents wave propagation from west to east and due to cyclic order of direction, the sector between 350°- 0° represents the same direction). These graphs are given in Figure 4.15. It can be seen from Figure 4.15 that the investigated interpolation methods seizes the peak points of the original series very closely but generally overestimate the results.

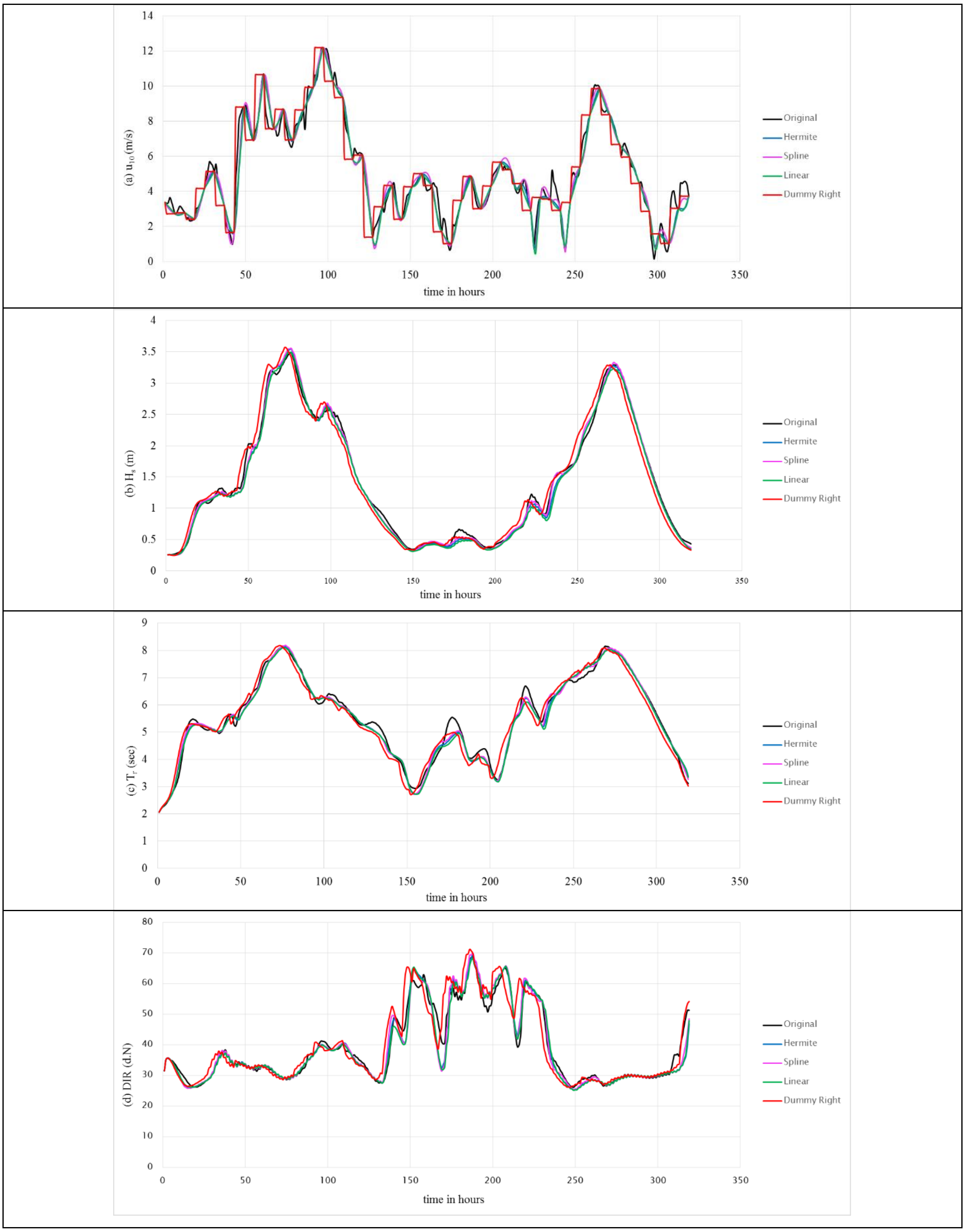


Figure 4.15. For SE_2 Time-Series graphs (a) Wind Velocity (b) Wave Height (c) Wave Period (d) Wave Direction

In addition to Figure 4.15, Figure 4.16 and Figure 4.17 has been prepared to study more closely the peak regions of wind velocity and wave height graphs. As it was for Point N_7, comparing Figure 4.16 wind velocity graph and Figure 4.17 wave height, it is clear that the interpolation methods are much competent with the original time-series for wave heights compared to the wind velocity.

It can be seen in Figure 4.16 and Figure 4.17 that there is a time lag between the peak points for wind velocity and wave height. The CFSR wind speed data reaches the peak point at hour 61 and the peak wave heights are observed within the hours 63 to 76. Also from Figure 4.17, it is observed that the Dummy Right interpolation method clearly shifts the storm backward.

Hermite, Linear, and Spline interpolation methods are the closest to the original curve compared to the Dummy Right interpolation method. Numerical verification for this is given in Table 4.11.

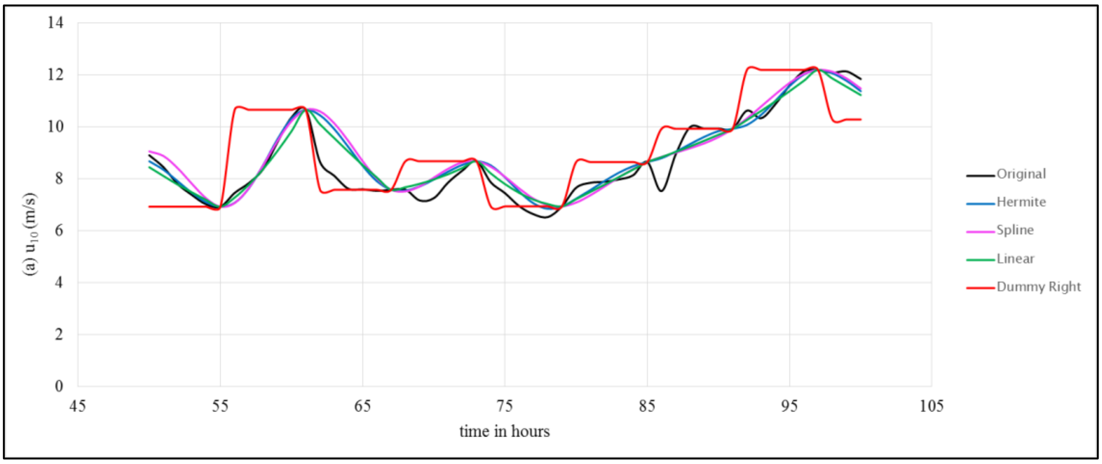


Figure 4.16. Wind Velocity time-series graph focused between 50-hours and 100-hours.

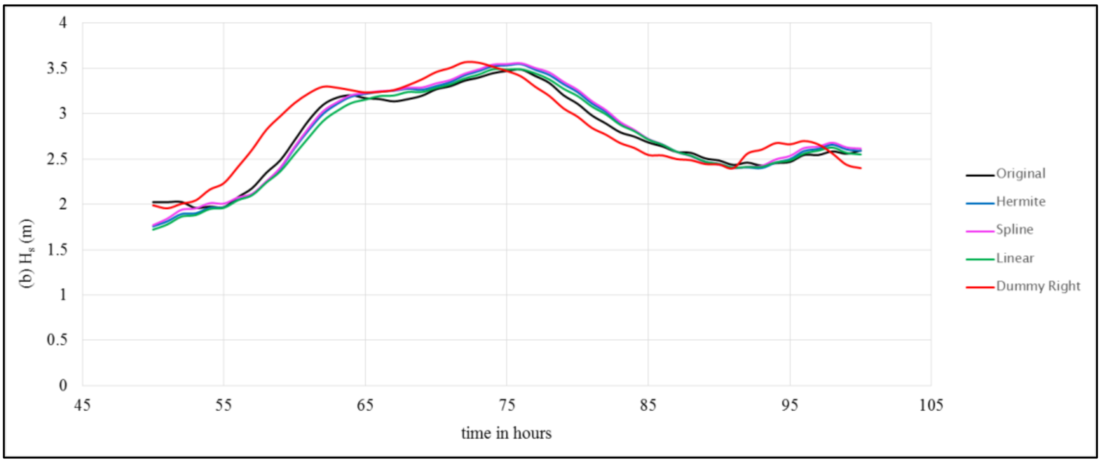


Figure 4.17. Wave Height time-series graph focused between 50-hours and 100-hours.

Even though both WAVEWATCH III and W61 results indicate that Linear interpolation method statistically performs the best among the investigated interpolation methods; the order of performances are different. It also can be observed from Table 4.11 that the magnitude of errors are quite different for WAVEWATCH III and W61.

Table 4.11. *Statistics for Storm Event Sinop at Point SE_2*

	Wind (Storm Event)	***WAVEWATCH III***		***W61***	***Wind (All Data)***
	MAE (%)	**MAE (%)**	**ER_{Hpeak} (%)**	**R. Error H_{100} (%)**	**MAE (%)**
Hermite	8.4423	5.3559	1.7202	6.0038	21.1389
Spline	8.9013	6.0775	1.9782	10.1786	20.9543
Linear	8.7459	6.2530	0.0573	4.2722	21.6264
Dummy Right	18.6593	10.0414	2.2936	8.0066	39.1146

The comparison of WAVEWATCH III with the W61 results indicates some differences of behavior between Point N_7 and SE_2. For Point N_7 it is seen that the evaluation of performances of interpolation methods are quite similar to each other.

Whereas for SE_2 it is observed the performances of the interpolation methods of WAVEWATCH III is much better than the performances for W61.

4.5.3. Comparison of WAVEWATCH III and Buoy Data

The WAVEWATCH III data has also been compared with the available buoy data for Gelendzhik and Sinop. The buoy data is plotted against the wave heights computed for the original CFSR data and the interpolated datasets. Figure 4.18 is given for Gelendzhik and Figure 4.19 is presented for Sinop. It is observed that even though the general trend of wave heights for the generated datasets matches the buoy data, the measured for wave heights are smaller than those computed for Gelendzhik. For Sinop, the generated datasets fails to estimate the first peak wave height of the storm.

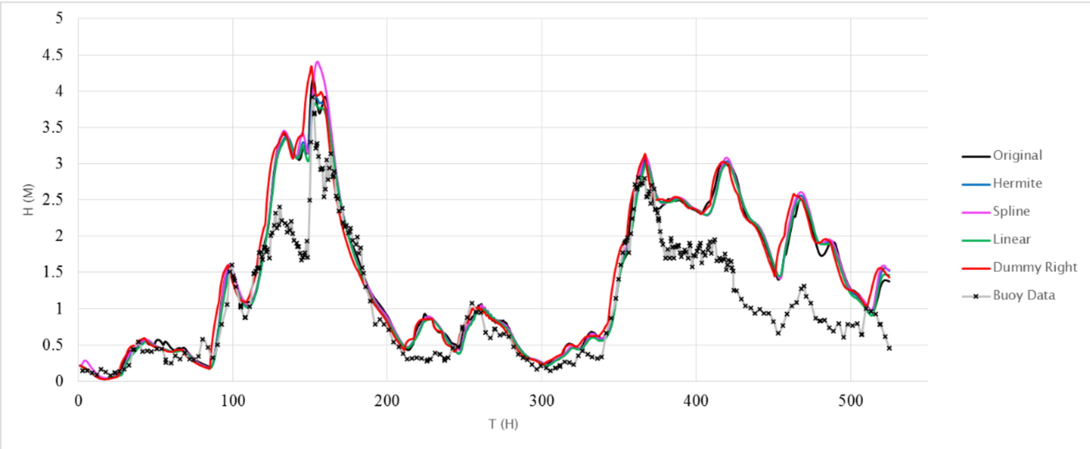


Figure 4.18. Wave Height time-series graph focused between 100-hours and 500-hours for Gelendzhik with buoy data.

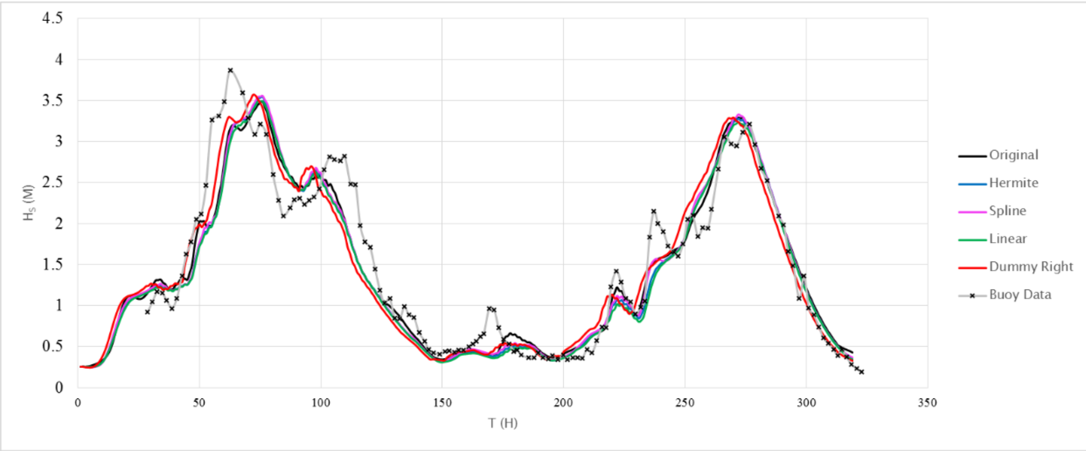


Figure 4.19. Wave Height time-series graph focused between 100-hours and 500-hours for Sinop with buoy data.

Although all interpolated datasets seem to behave similarly when compared to buoy data, for the first peak of Gelendzhik event, Spline method deviates from the rest and do not reflect the actual trend of the measured data. Considering that Spline is the most commonly used method, this result again points out the fact that selection of interpolation method might have significant effect on modelling of individual events.

4.5.4. WAVEWATCH III for the Black Sea (25 location)

A storm event from 12.12.2009 at 00.00 to 17.12.2009 at 23.00 has been selected to analyze for all of the selected 25 points within the Black Sea. The event duration is 6 days. It is known from archived news coverages that during this dates a powerful storm has affected the whole Black Sea region and wave heights up to 12.00 meters were observed by local people in some regions. So, it has been decided to analyze this event for all selected 25 points through the Black Sea region.

Using WAVEWATCH III output data, hourly time-series graphs have been prepared for wind velocity, wave height, wave period and wave direction (0° represents wave propagation from west to east and due to cyclic order of direction, the sector between

350°- 0° represents the same direction) for all 25 points. These graphs are given in Appendix B.

Mean Average Errors (MAE) and the relative errors between the maximum wave heights of the original series and the interpolated series (ER_{Hpeak}) are given in Table 4.12.

Table 4.12. *Mean Absolute Errors of wave heights for each interpolation method compared to the original wave height dataset and the error of the maximum wave height compared to the original maximum wave heights for each interpolation*

	HERMITE		SPLINE		LINEAR		DUMMY RIGHT	
	MAE (%)	**ERR_{PEAK} (%)**	**MAE (%)**	**ERR_{PEAK} (%)**	**MAE (%)**	**ERR_{PEAK} (%)**	**MAE (%)**	**ERR_{PEAK} (%)**
SW_1	3.6377	4.1966	3.7463	2.9214	4.2893	5.0777	7.0635	4.8226
SW_2	4.7755	0.1895	4.3633	1.6487	5.9754	2.3309	7.7632	3.6195
SW_3	4.8462	9.2525	5.0152	7.2644	6.4075	12.7700	9.2009	5.0468
SW_4	4.0108	14.3543	4.1349	11.6756	5.0354	18.2339	10.9526	10.9366
SW_5	3.5646	6.0037	3.4414	2.2491	5.2989	11.6914	11.5625	0.0558
SW_6	3.6624	2.6821	3.3817	2.7007	5.6076	9.2568	11.2480	4.0417
SW_7	4.4591	13.6716	3.7387	8.7638	6.9152	18.4317	10.7451	10.8856
SW_8	5.2390	16.5026	4.7910	13.7173	7.3211	20.5864	8.3781	14.8482
SE_1	7.0355	10.7759	9.1868	6.3935	6.9395	15.1774	13.8145	8.1199
SE_2	5.5490	10.2830	9.7577	3.7028	5.5286	14.1509	13.1556	9.8585
SE_3	7.1024	9.5326	8.2945	4.3042	7.1755	14.2593	12.8961	5.2812
SE_4	5.6903	5.4123	5.0919	2.0037	6.2607	10.7324	11.3247	2.2340
SE_5	4.8851	8.1990	5.1705	0.5655	5.9927	13.8535	11.0267	4.9477
SE_6	5.9048	7.0643	6.5175	1.8119	5.9214	14.5562	14.4859	1.9951
SE_7	7.0161	12.5000	7.1099	6.4423	7.4327	18.5256	14.6484	8.9423
SE_8	7.0314	9.3940	6.5134	3.5594	7.6670	16.9182	14.7650	6.5781
SE_9	7.4801	10.5945	6.2654	3.8846	8.5334	15.8917	14.3361	9.1230
N_1	2.9782	0.2315	3.2116	1.3025	3.4330	0.9262	9.9018	1.9103
N_2	2.9697	0.1441	3.3155	1.0810	2.9008	0.4084	14.2150	0.3603
N_3	5.0983	3.2826	5.2069	2.8022	5.3242	4.2434	12.4559	2.3619
N_4	4.9001	3.2656	5.1329	2.0682	5.5508	5.3338	11.8000	0.4354
N_5	4.5615	7.7218	4.3670	7.7218	5.8031	10.4053	11.8737	3.8061
N_6	3.8726	5.0847	3.2989	3.8136	5.0706	6.6102	9.0867	1.1582
N_7	4.7732	5.6604	5.0528	5.3361	5.2677	6.3974	11.4653	5.1592
N_8	5.4348	20.5852	5.0054	14.4529	6.5055	21.5013	9.9254	18.1170

From Table 4.12 it has been observed that ER_{Hpeak} is smaller than MAE at 5 Points for Linear, 7 points for Hermite, 16 points for Spline and 22 Points for Dummy Right interpolation methods. Considering that ER_{Hpeak} represents the difference between the maximum wave heights; it is concluded that for this particular storm event, interpolation methods Spline and Dummy Right represents the peaks of the original curve much better than the interpolation methods Hermite and Linear.

Also, it has been seen that the Spline interpolation method have the lowest ER_{Hpeak} for 13 of the selected 25 points. In fact, for all of the points within the South East sub-region, Spline interpolation method performs the best among the investigated methods. Dummy Right interpolation method performs the best for 8 of the points whereas Hermite performs the best for 4 of the selected points.

For 21 of the selected 25 points, Linear interpolation has the highest ER_{Hpeak}. In fact, for all of the points within the South East sub-region, Linear interpolation method performs the worst among the investigated methods. Dummy Right and Spline interpolation methods perform the worst for 2 points each.

For the MAE, which indicates the average error of the complete wave heights computed with respect to the original series, Dummy Right interpolation method performs the worst among the investigated interpolation methods for all 25 points. This result is compatible with the wind analysis. For 11 of the selected 25 points, Hermite interpolation method have the lowest MAE. Spline interpolation method also performs the best for 11 points and for 3 points Linear interpolation method performs the best.

The differences between the ranking of performance between MAE and ER_{Hpeak} indicate that an interpolation method which estimates the hourly wave heights more accurately than the others may fail to estimate the peak wave heights. For instance, at Point N_8 the MAE is calculated between ~5.00% to ~ 9.00%, depending on the interpolation method. For the same point, the ER_{Hpeak} differs between ~14.50% to ~ 21.50%.

It has been observed that for 17 of the selected 25 points, the peak wave heights according to the Dummy Right interpolation method occurs 2 - 4 hours prior to the occurrence of the peak wave heights for the original series. The mathematical formula for the Dummy Right interpolation method is explained as filling the missing data equal to the known value in their right side in a series. Since during the interpolation of the wind series the Dummy Right method reaches to the peak wind speed up to 6 hours before the original CFSR dataset, it is expected that the peak wave heights also produced earlier.

For instance, the wind speed data for point SW_3 is given in Figure 4.20. It is seen from the graph that the peak wind velocity for the Dummy Right interpolation has been generated between hours 24 and 30, whereas the peak velocity according to the CFSR dataset occurs at hour 34. In correspondence to the wind data, the peak wave height for the Dummy Right interpolation method occurs at hour 31 while the peak wave height for the original CFSR data occurs at hour 34.

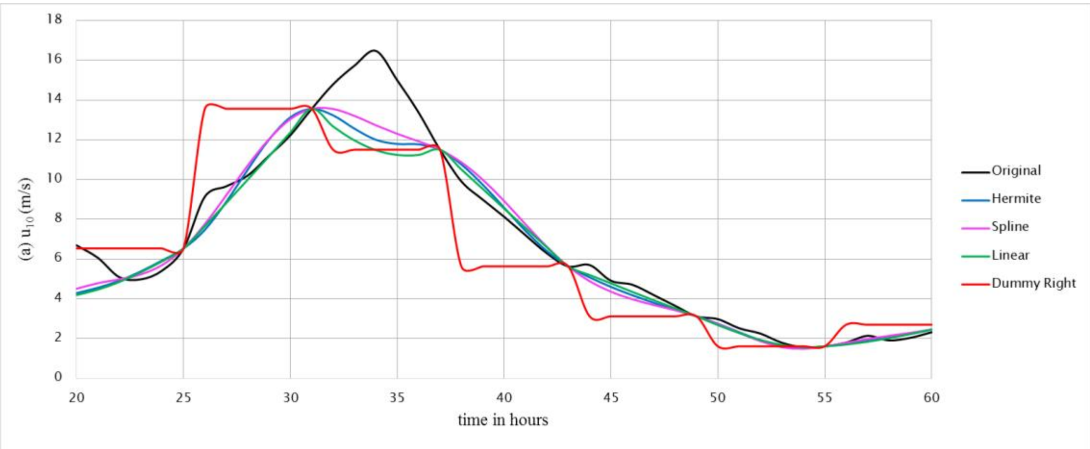


Figure 4.20. Wind Velocity time-series graph focused between 20 hours and 60 hours.

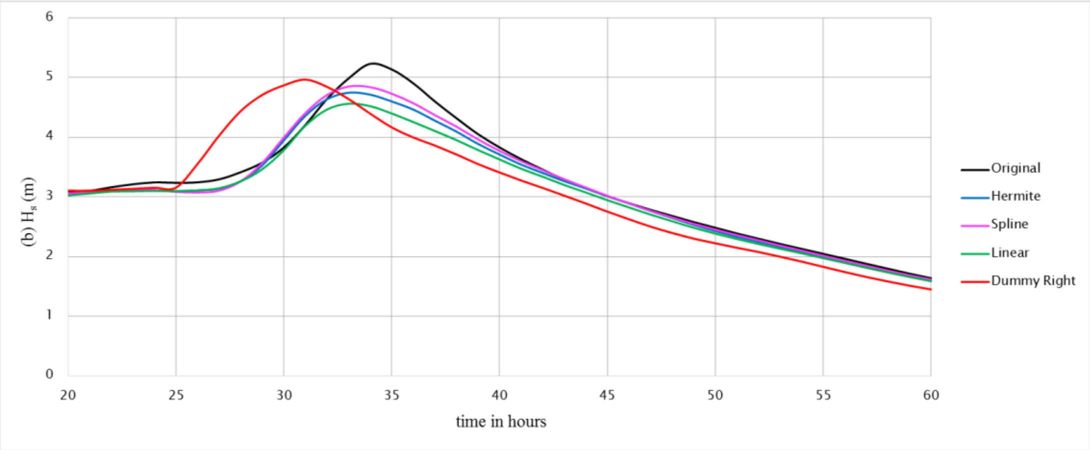


Figure 4.21. Wave Height time-series graph focused between 20 hours and 60 hours.

For Point SW_3, Figure 4.20 and Figure 4.21show that both the peak velocity and the peak wave height are observed at the same hour but this is not the case for many other points. For instance, for Point SE_5 peak wave height occurs 5 hours earlier for Spline interpolation method compared to the original CFSR dataset. Since wind speed energy cumulatively forms the wave height, for nearly most cases, the peak wave heights are observed 2 - 10 hours after the peak wind velocity.

CHAPTER 5

CONCLUSION

In this research, performances of different interpolation methods for wave analysis in the Black Sea basin were evaluated and compared. Also, the compatibility of the performances of different interpolation methods for wind analysis, that were obtained from the research by Güler et al. (2016a, 2016b), and wave analysis in this research were investigated.

For these purposes, two different wave generation models were used: W61 and WAVEWATCH III. Generated wave results from W61 were used to conduct long term wave analyses and extreme wave analyses for the selected 25 points within the Black Sea basin. WAVEWATCH III was used to investigate 3 separate extreme storm events for different locations within the Black Sea basin.

The long term analysis results obtained from datasets generated from W61 showed that; among the four interpolation methods analyzed for each of the 25 points, a definite best interpolation method to be used cannot be determined for the Black Sea. The best interpolation method for each point is shown on the Black Sea map in Figure 5.1.

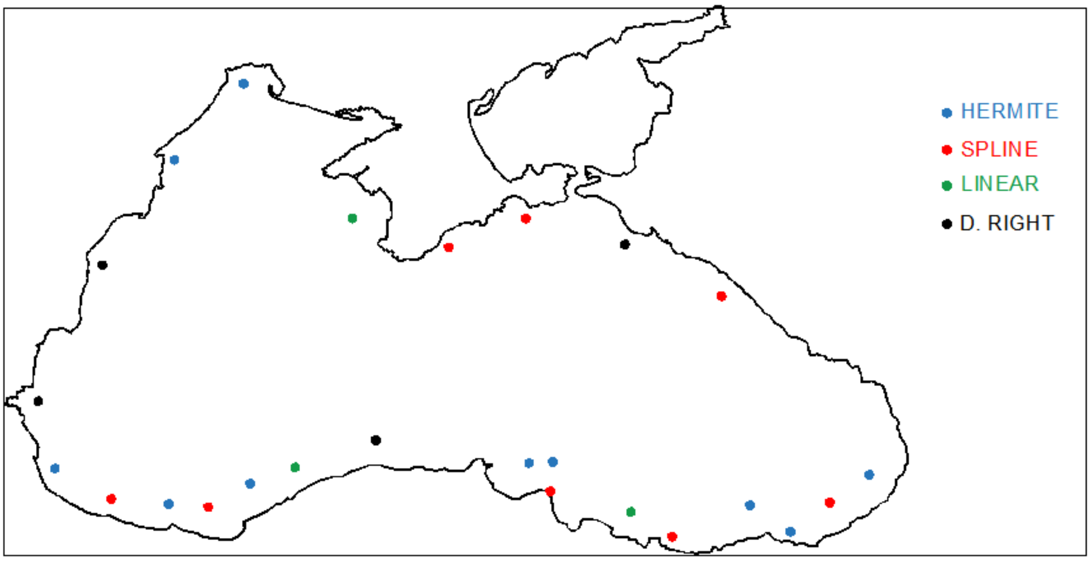


Figure 5.1. Best Interpolation Methods for Long Term Wave Analysis

Additionally, a definite best interpolation method to be preferred above the others cannot be determined for extreme wave analysis either. The best interpolation method for each point is shown on the Black Sea map in Figure 5.2.

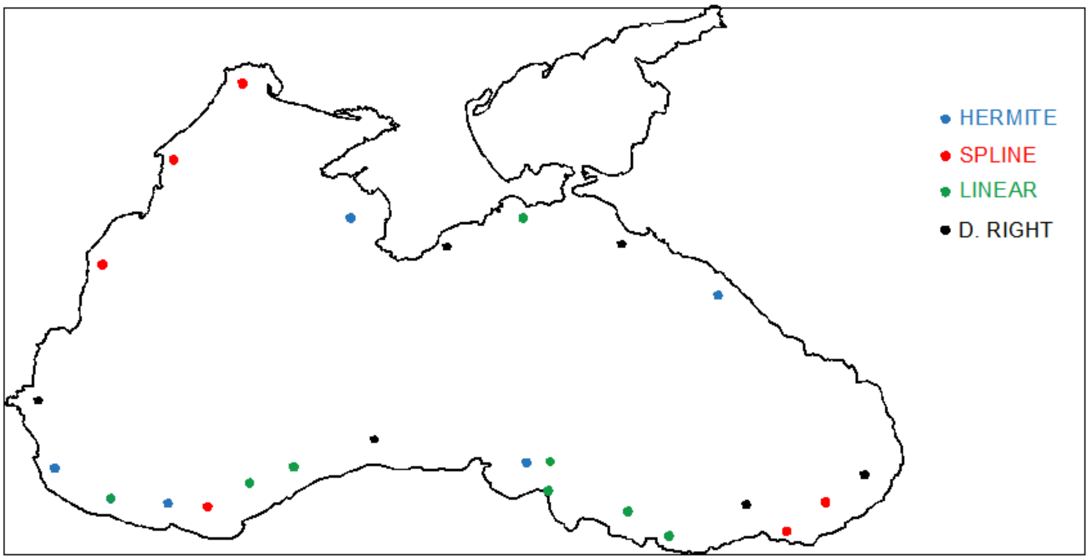


Figure 5.2. Best Interpolation Methods for Extreme Wave Analysis

According to the final results of the research by Güler et al. (2016a, 2016b), performance rankings of different interpolation methods in the Black Sea basin shows a consistent pattern. One of the main aims of this study was to determine whether the ranking of performances for wave analysis was compatible with the ranking of performances for the wind analysis. As it was stated above, unlike wind analysis results, a definite best interpolation method cannot be determined for wave analyses. What is more, it was seen that the ranking performance of wind and wave analysis were not compatible. A comparison table of the best interpolation methods for wind analyses results with the best interpolation methods for the long term and extreme wave analyses results are given in Table 5.1. It can also be seen from Table 5.1 that the interpolation method with the best performance is generally different for long term and extreme wave analyses.

Table 5.1. *The Best Interpolation Method for Wind, Long Term Wave, and Extreme Wave Analyses.*

POINT	REGION	WIND (ALL DATA)	LONG TERM WAVE ANALYSIS	EXTREME WAVE ANALYSIS
		BEST	BEST	BEST
SW_1	*SOUTH WEST REGION OF BLACK SEA*	HERMITE	DUMMY RIGHT	DUMMY RIGHT
SW_2		SPLINE	HERMITE	HERMITE
SW_3		SPLINE	SPLINE	LINEAR
SW_4		SPLINE	HERMITE	HERMITE
SW_5		SPLINE	SPLINE	SPLINE
SW_6		SPLINE	HERMITE	LINEAR
SW_7		SPLINE	LINEAR	LINEAR
SW_8		HERMITE	DUMMY RIGHT	DUMMY RIGHT
SE_1	*SOUTH EAST REGION OF BLACK SEA*	SPLINE	HERMITE	HERMITE
SE_2		SPLINE	HERMITE	LINEAR
SE_3		SPLINE	SPLINE	LINEAR
SE_4		SPLINE	LINEAR	LINEAR
SE_5		SPLINE	SPLINE	LINEAR
SE_6		HERMITE	HERMITE	DUMMY RIGHT
SE_7		SPLINE	HERMITE	SPLINE
SE_8		HERMITE	SPLINE	SPLINE
SE_9		HERMITE	HERMITE	DUMMY RIGHT
N_1	*NORTH REGION OF BLACK SEA*	SPLINE	DUMMY RIGHT	SPLINE
N_2		SPLINE	HERMITE	SPLINE
N_3		HERMITE	HERMITE	SPLINE
N_4		HERMITE	LINEAR	HERMITE
N_5		HERMITE	SPLINE	DUMMY RIGHT
N_6		HERMITE	SPLINE	LINEAR
N_7		HERMITE	DUMMY RIGHT	DUMMY RIGHT
N_8		HERMITE	SPLINE	HERMITE

In Section 2.3 it was stated that the interpolation methods Dummy Right and Dummy Left performed the worst among the nine interpolation methods for wind analysis. The interpolation method with the worst performance according to the statistical parameters that were calculated varies for the selected 25 points for both long term wave analysis and extreme wave analysis. The comparison of the worst interpolation method for wind, long term, and extreme wave analyses is given in Table 5.2. Also, it can be seen from Table 5.2 that at 12 points out of the 25 that were investigated, the worst interpolation methods for the long term and extreme wave analyses were different from each other.

Table 5.2. *The Worst Interpolation Method for Wind, Long Term Wave, and Extreme Wave Analyses.*

POINT	REGION	WIND (ALL DATA)	LONG TERM WAVE ANALYSIS	EXTREME WAVE ANALYSIS
		WORST	WORST	WORST
SW_1	*SOUTH WEST REGION OF BLACK SEA*	DUMMY RIGHT	HERMITE	LINEAR
SW_2		DUMMY RIGHT	DUMMY RIGHT	SPLINE
SW_3		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
SW_4		DUMMY RIGHT	LINEAR	DUMMY RIGHT
SW_5		DUMMY LEFT	DUMMY LEFT	DUMMY LEFT
SW_6		DUMMY RIGHT	SPLINE	SPLINE
SW_7		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
SW_8		DUMMY RIGHT	SPLINE	LINEAR
SE_1	*SOUTH EAST REGION OF BLACK SEA*	DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
SE_2		DUMMY RIGHT	LINEAR	SPLINE
SE_3		DUMMY LEFT	DUMMY LEFT	SPLINE
SE_4		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
SE_5		DUMMY RIGHT	LINEAR	SPLINE
SE_6		DUMMY RIGHT	DUMMY RIGHT	HERMITE
SE_7		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
SE_8		DUMMY RIGHT	DUMMY RIGHT	HERMITE
SE_9		DUMMY RIGHT	DUMMY RIGHT	LINEAR
N_1	*NORTH REGION OF BLACK SEA*	DUMMY RIGHT	LINEAR	LINEAR
N_2		DUMMY RIGHT	DUMMY RIGHT	LINEAR
N_3		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
N_4		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
N_5		DUMMY RIGHT	LINEAR	LINEAR
N_6		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT
N_7		DUMMY RIGHT	LINEAR	LINEAR
N_8		DUMMY RIGHT	DUMMY RIGHT	DUMMY RIGHT

The investigated 25 points have been selected in order to represent the behavior throughout the Black Sea basin and the variable performances of interpolation methods for these points indicate that using interpolation methods introduce an additional error for the designs. The research by Van Vledder G. and Akpınar A. (2015) argued that the temporal resolution of the wind fields has an insignificant effect wave model in the Black Sea. This argument is also supported by the findings of the research by Erol C. O. (2014). So, it can be said that, for the Black Sea region, using wind fields with lower temporal resolutions for wave generation models may produce more reliable results than using interpolation methods to increase the temporal resolutions of the available wind fields.

Another aim of the study was to determine the magnitude of errors of the interpolated wave height datasets compared to the original datasets. At the end of the study, it is seen that the magnitude of errors for the wave heights are smaller than the magnitude of errors for wind speeds. The most probable cause of this is that the errors for wind speeds were calculated from large datasets consisting wind speed data of 32 years whereas the errors for the wave heights were obtained comparing two singular values. Also, in nature, the wind velocity fluctuates much more compared to the fluctuations in the wave heights as also can be observed from the WAVEWATCH III graphs. The influence of change in characteristics of wind on the generation of waves requires a longer duration, which is reflected in slower and less fluctuation of wave characteristics. Therefore, the slow change in the wave generation could be a reason for lower errors compared to the wind comparisons regarding the use of different interpolation techniques.

Even though the performances of the interpolation methods vary for each point, the average error computation shows that Piecewise Cubic Hermite Polynomial (Hermite) interpolation method has the lowest average relative error (2.33% for long term analysis and 3.10% for extreme wave analysis) among the inspected interpolation methods. Hermite interpolation method was also classified as the method with the lowest mean average error for wind analyses. Also Dummy Right interpolation method has the highest average relative error for the 25 points investigated (5.72% for long term analysis and 4.41% for extreme wave analysis) as it was for the wind analysis (Average statistics for Dummy Left interpolation method were left out of this comparison since this interpolation method was analyzed for only 2 points.). An error comparison table for wind, long term wave and extreme wave analyses of the selected 25 points are given in Table 5.3.

Table 5.3. *Average Error Statistics for Wind, Long Term and Extreme Wave Analyses*

	Wind (All Data) Mean Average Error (%)	**Long Term Wave Analysis Average Relative Error (%)**	**Extreme Wave Analysis Average Relative Error (%)**
Piecewise Cubic Hermite Interpolation	21.63	2.33	3.10
Cubic Spline Interpolation	21.53	2.63	3.37
Linear Interpolation	22.06	3.74	3.38
Dummy Right Interpolation	39.90	5.72	4.41

In addition to the W61 analysis, WAVEWATCH III calibrated by Kirezci (2016) for the Black Sea basin also was used in this research. The best performing interpolation methods for a storm event between dates 12.12.2009 and 17.12.2009 WAVEWATCH III analysis is given in Table 5.4.

Table 5.4. *The Best Interpolation Method for Wind Analysis and WAVEWATCH III Analysis*

POINT	REGION	WIND (ALL DATA)	WAVEWATCH III	
		BEST	BEST MAE	BEST ER_{Hpeak}
SW_1	*SOUTH WEST REGION OF BLACK SEA*	HERMITE	HERMITE	SPLINE
SW_2		SPLINE	SPLINE	HERMITE
SW_3		SPLINE	HERMITE	DUMMY RIGHT
SW_4		SPLINE	HERMITE	DUMMY RIGHT
SW_5		SPLINE	SPLINE	DUMMY RIGHT
SW_6		SPLINE	SPLINE	HERMITE
SW_7		SPLINE	SPLINE	SPLINE
SW_8		HERMITE	SPLINE	SPLINE
SE_1	*SOUTH EAST REGION OF BLACK SEA*	SPLINE	LINEAR	SPLINE
SE_2		SPLINE	LINEAR	SPLINE
SE_3		SPLINE	HERMITE	SPLINE
SE_4		SPLINE	SPLINE	SPLINE
SE_5		SPLINE	HERMITE	SPLINE
SE_6		HERMITE	HERMITE	SPLINE
SE_7		SPLINE	HERMITE	SPLINE
SE_8		HERMITE	SPLINE	SPLINE
SE_9		HERMITE	SPLINE	SPLINE
N_1	*NORTH REGION OF BLACK SEA*	SPLINE	HERMITE	HERMITE
N_2		SPLINE	LINEAR	HERMITE
N_3		HERMITE	HERMITE	DUMMY RIGHT
N_4		HERMITE	HERMITE	DUMMY RIGHT
N_5		HERMITE	SPLINE	DUMMY RIGHT
N_6		HERMITE	SPLINE	DUMMY RIGHT
N_7		HERMITE	HERMITE	DUMMY RIGHT
N_8		HERMITE	SPLINE	SPLINE

To sum up, even though the Hermite interpolation method has the lowest average relative error of the selected 25 points for the long term and extreme wave analysis, it is not possible to recommend this method for every location within the Black Sea. The lack of a definite best interpolation method for wave analysis may be explained that, unlike wind analysis, there are many physical parameters, spectral shapes, and energy levels that affect the wave generation. Wind speed is a crucial parameter for the generation of wind waves but for each different location, another one of these factors may change influence the performance of the interpolation methods. In most of the previous research, calibrations were made using the measured wave height data and part of the divergence observed before the calibration may be a result of the interpolation method used.

In this study, basic statistical parameters were used to evaluate the performances of the interpolation methods; for future research more advanced statistical approaches may be experimented to find a pattern of performance. Also, all of the investigated 25 points were selected close to the coastlines. Wind analysis results indicate that a more definite pattern may also exist for wave analysis at relatively open waters compared to the points investigated.

This research was focused on the Black Sea basin. Same wind and wave analyses may be applied to evaluate and compare the performances of different interpolation methods for the Mediterranean and other possible locations. A joint investigation of these future researches with the research on the Black Sea basin may present a better understanding of the performances of different interpolation methods for wind and wave analyses.

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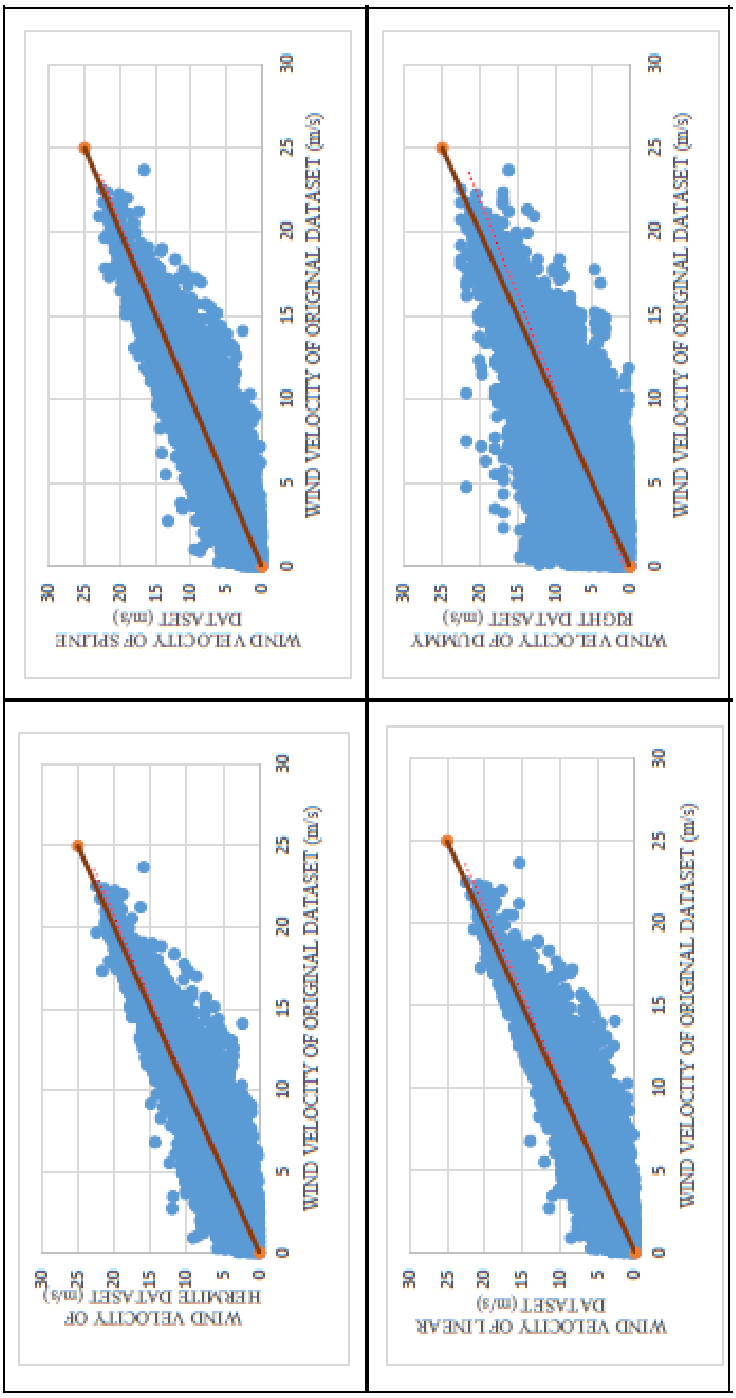
APPENDICES

A. WIND CLIMATE AND WAVE ANALYSIS USING W61

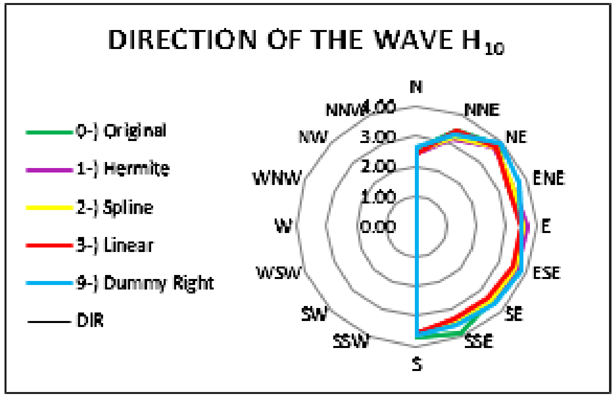
POINT SW_1 - N: 42.62° E: 28.13°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.9172	0.0518	0.1369	0.1600	0.9970	0.1500
2	Spline	0.9147	0.0196	0.1371	0.1594	1.0123	0.1502
3	Linear	0.9119	0.0942	0.1458	0.1664	0.9848	0.1597
9	D. Right	0.6961	0.0002	0.2582	0.3413	1.0160	0.2828

Figure A.1. Wind Analysis of Point SW_1

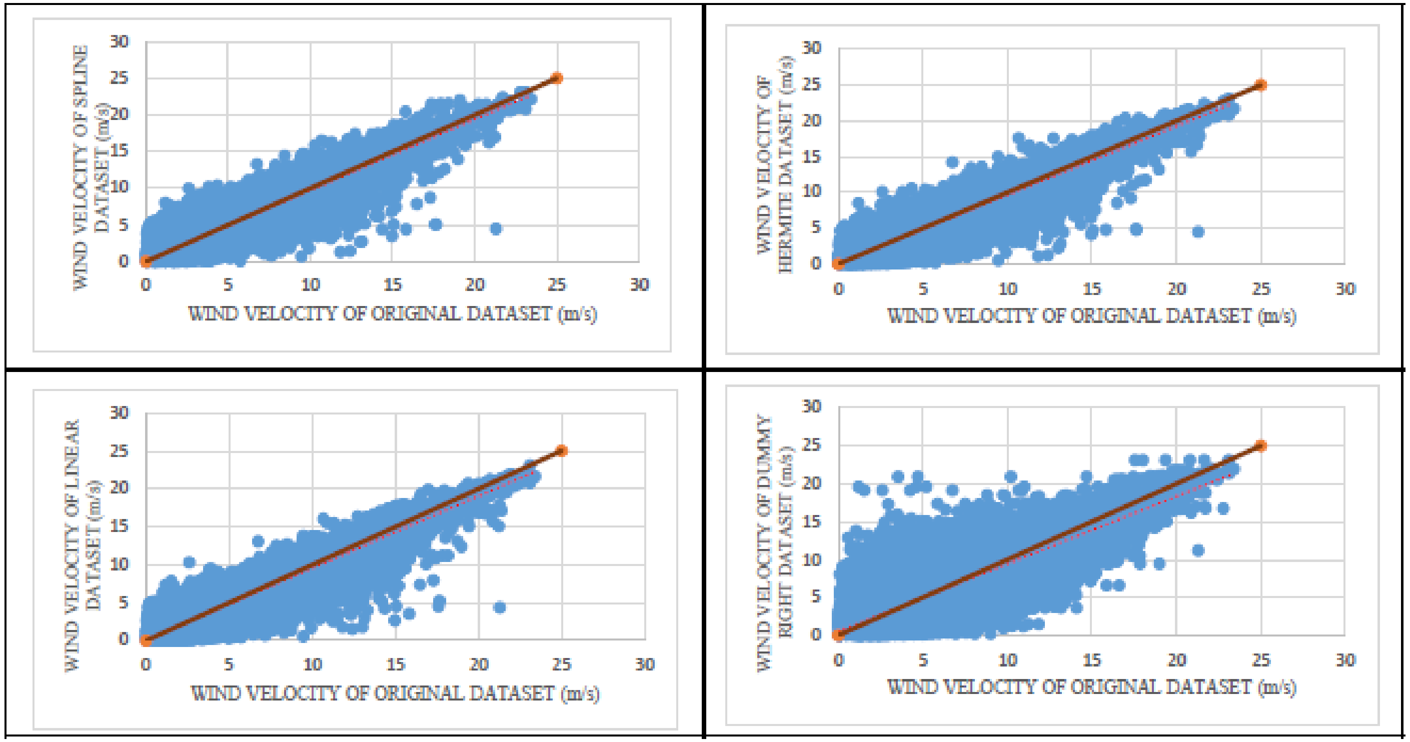
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.58	9.18	3.88	7.65	2.71	6.39	2.26	5.84	-	-	-	-
1-) Hermite	5.88	9.40	3.70	7.45	2.63	6.28	2.21	5.76	5.36	-4.70	-3.10	-2.20
2-) Spline	5.50	9.08	3.78	7.53	2.64	6.30	2.23	5.79	-1.50	-2.68	-2.41	-1.45
3-) Linear	5.50	9.10	3.75	7.52	2.60	6.25	2.19	5.74	-1.38	-3.25	-4.09	-3.31
9-) Dummy Right	5.75	9.17	3.94	7.59	2.69	6.27	2.25	5.73	3.01	1.44	-0.58	-0.66



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.89	11.94	7.21	12.22	-	-
1-) Hermite	6.75	11.85	7.07	12.13	-1.98	-2.02
2-) Spline	6.68	12.08	6.98	12.35	-2.95	-3.23
3-) Linear	6.64	11.56	6.96	11.84	-3.52	-3.44
9-) Dummy Right	6.77	12.46	7.08	12.75	-1.70	-1.85

Figure A.2. Wave Analysis of Point SW_1

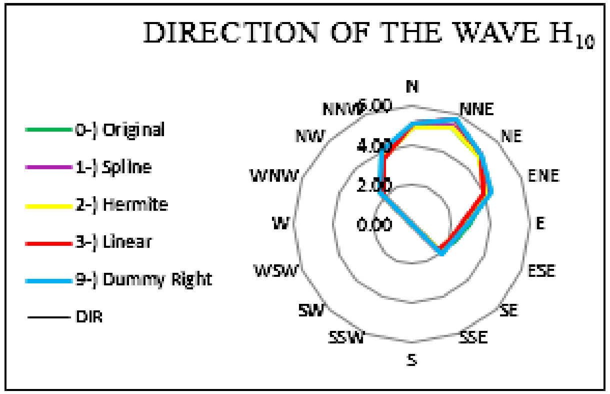
POINT SW_2 - N: 41.68° E: 28.44°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.9122	0.0474	0.1414	0.1631	1.0068	0.1549
2	Hermite	0.9130	0.0704	0.1429	0.1649	0.9918	0.1566
3	Linear	0.9086	0.1009	0.1502	0.1704	0.9772	0.1645
9	D. Right	0.7171	0.0316	0.2511	0.3170	1.0138	0.2751

Figure A.3. Wind Analysis of Point SW_2

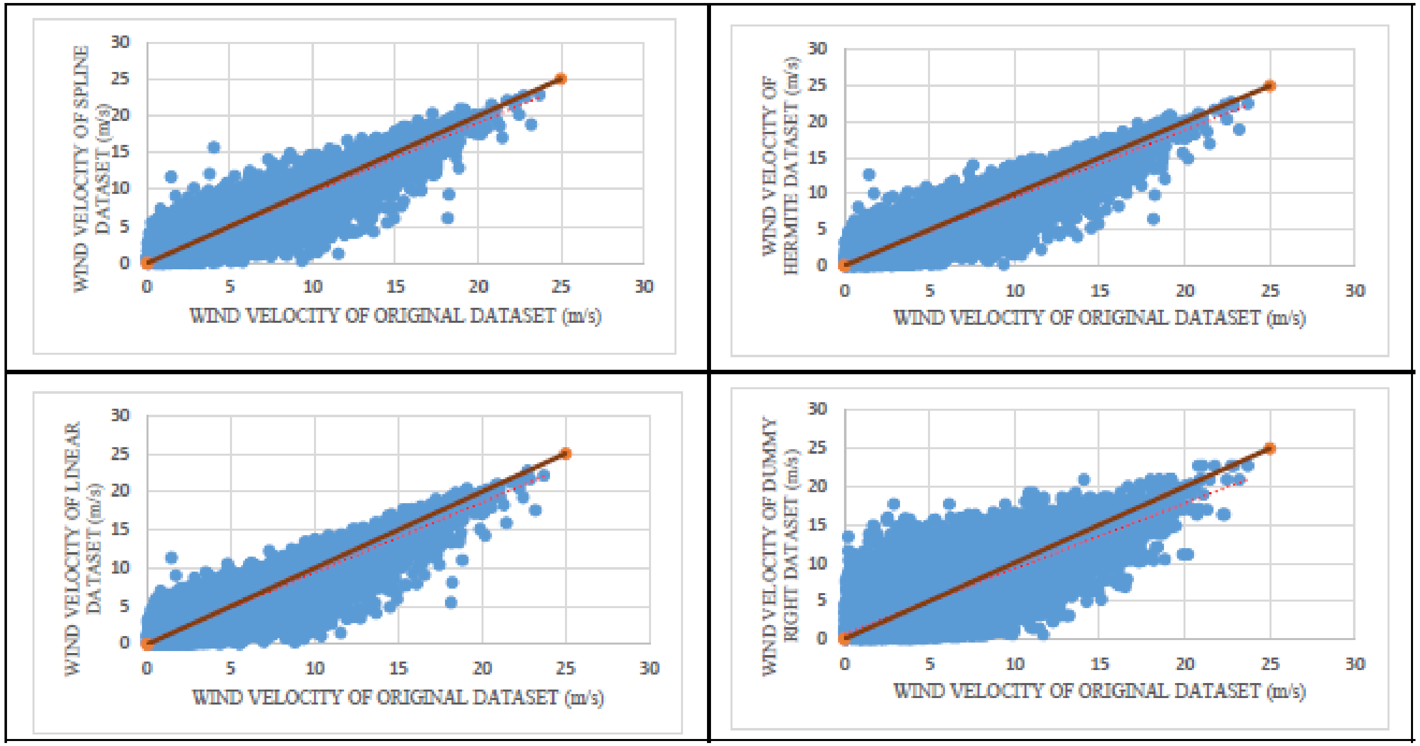
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.13	10.53	5.27	9.06	3.97	7.86	3.41	7.29	-	-	-	-
1-) Spline	7.36	10.67	5.42	9.16	4.07	7.93	3.48	7.34	3.21	2.84	2.38	2.08
2-) Hermite	7.18	10.53	5.32	9.06	4.02	7.88	3.46	7.31	0.73	0.92	1.16	1.31
3-) Linear	7.86	11.02	5.68	9.37	4.16	8.02	3.51	7.36	10.25	7.83	4.78	2.75
9-) Dummy Right	7.98	11.00	5.76	9.34	4.21	7.99	3.54	7.33	11.96	9.32	6.00	3.80



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.63	11.36	9.03	11.62	-	-
1-) Spline	8.76	10.91	9.20	11.17	1.58	1.87
2-) Hermite	8.61	11.08	9.02	11.34	-0.20	-0.14
3-) Linear	8.56	10.97	8.96	11.22	-0.75	-0.77
9-) Dummy Right	8.72	11.27	9.15	11.54	1.10	1.34

Figure A.4. Wave Analysis of Point SW_2

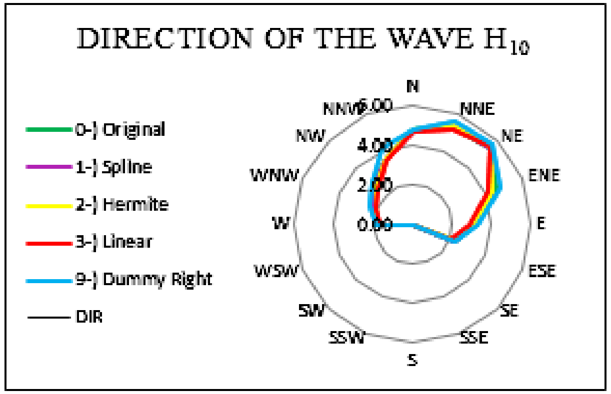
POINT SW_3 - N: 41.37° E: 29.38°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8777	0.0693	0.1602	0.1822	0.9928	0.1755
2	Hermite	0.8778	0.0964	0.1630	0.1849	0.9750	0.1785
3	Linear	0.8733	0.1304	0.1704	0.1913	0.9558	0.1867
9	D. Right	0.6434	0.0480	0.2693	0.3413	1.0088	0.2950

Figure A.5. Wind Analysis of Point SW_3

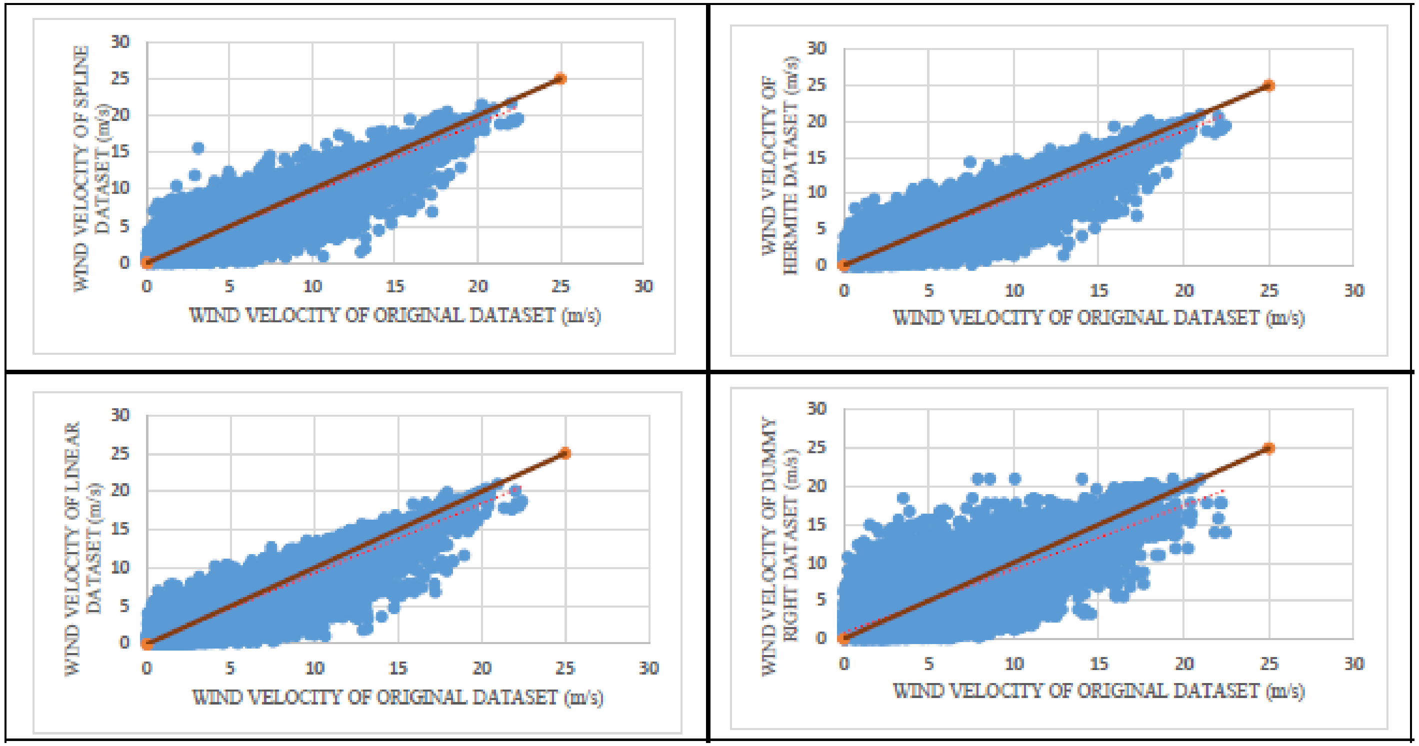
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.24	10.71	5.48	9.32	4.25	8.20	3.72	7.67	-	-	-	-
1-) Spline	7.44	10.80	5.49	9.27	4.18	8.09	3.61	7.52	2.73	0.10	-1.65	-2.77
2-) Hermite	7.47	10.81	5.50	9.27	4.17	8.08	3.60	7.51	3.16	0.31	-1.75	-3.06
3-) Linear	7.54	10.87	5.57	9.34	4.20	8.11	3.61	7.51	4.14	1.73	-1.15	-2.98
9-) Dummy Right	7.80	10.91	5.64	9.28	4.28	8.08	3.69	7.51	7.63	2.99	0.73	-0.70



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.98	11.31	9.42	11.59	-	-
1-) Spline	9.09	11.37	9.56	11.67	1.22	1.52
2-) Hermite	9.04	11.25	9.52	11.55	0.70	1.02
3-) Linear	8.98	11.11	9.46	11.40	0.04	0.37
9-) Dummy Right	9.12	11.44	9.59	11.73	1.61	1.83

Figure A.6. Wave Analysis of Point SW_3

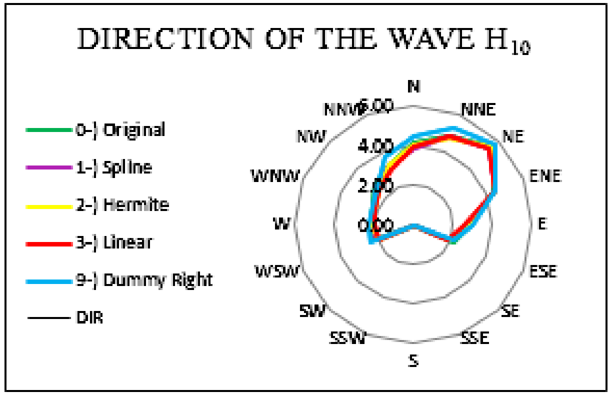
POINT SW_4 - N: 41.37° E: 30.31°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8644	0.0608	0.1761	0.2133	0.9869	0.1930
2	Hermite	0.8623	0.0981	0.1811	0.2187	0.9698	0.1984
3	Linear	0.8544	0.1437	0.1924	0.2285	0.9521	0.2108
9	D. Right	0.6003	0.0316	0.2988	0.4066	1.0009	0.3273

Figure A.7. Wind Analysis of Point SW_4

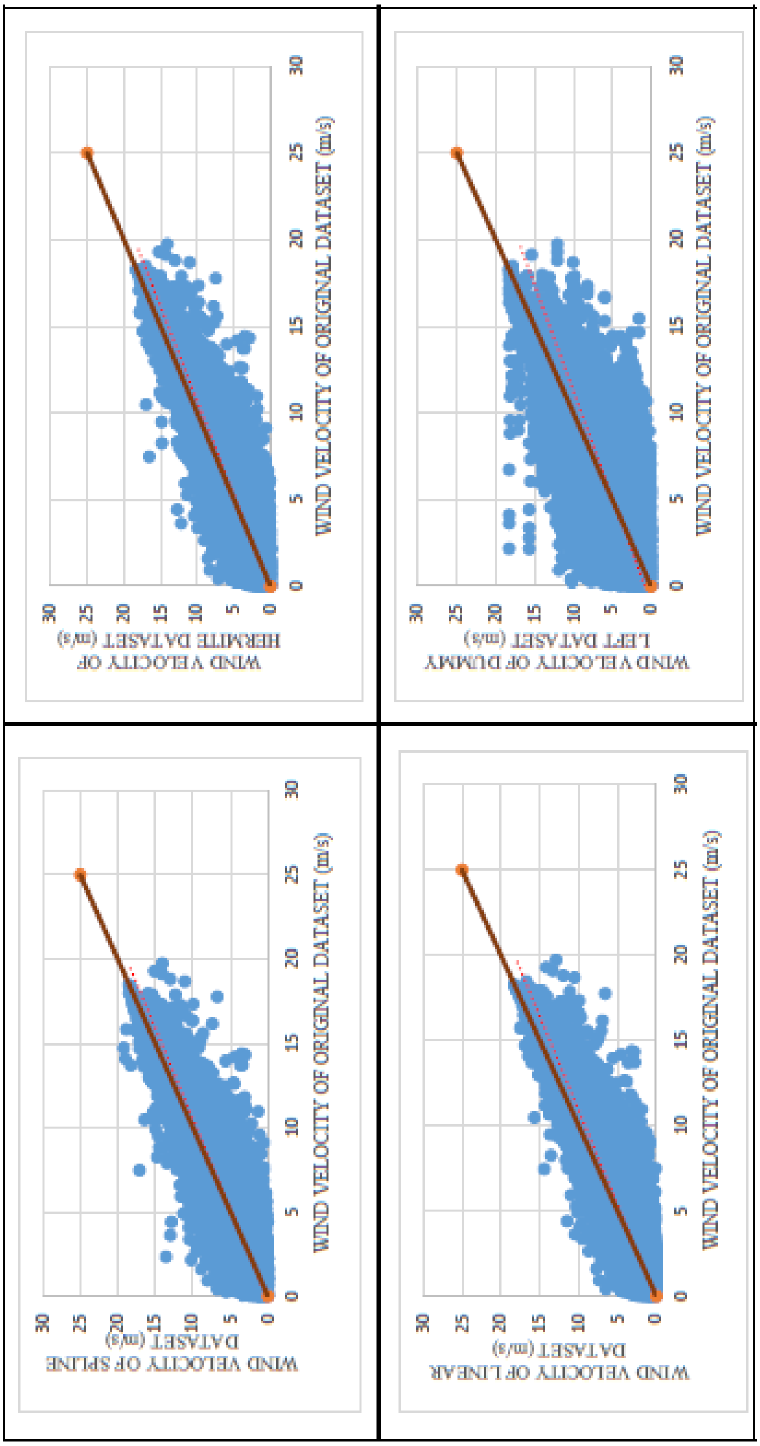
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.39	10.86	5.63	9.48	4.40	8.38	3.87	7.86	-	-	-	-
1-) Spline	7.14	10.63	5.44	9.28	4.25	8.20	3.74	7.69	-3.41	-3.37	-3.32	-3.28
2-) Hermite	7.31	10.74	5.54	9.35	4.30	8.24	3.77	7.71	-1.15	-1.66	-2.25	-2.63
3-) Linear	7.15	10.64	5.44	9.28	4.24	8.19	3.72	7.68	-3.22	-3.40	-3.63	-3.76
9-) Dummy Right	7.62	10.82	5.76	9.41	4.46	8.27	3.89	7.74	3.13	2.27	1.26	0.62



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	9.07	11.51	9.54	11.80	-	-
1-) Spline	8.93	11.32	9.41	11.62	-1.47	-1.40
2-) Hermite	9.02	11.42	9.52	11.73	-0.51	-0.20
3-) Linear	8.99	11.38	9.49	11.69	-0.85	-0.47
9-) Dummy Right	9.29	11.92	9.83	12.26	2.44	3.08

Figure A.8. Wave Analysis of Point SW_4

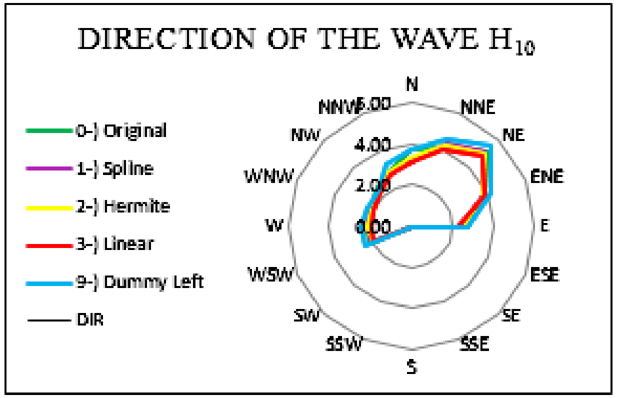
POINT SW_5 - N: 41.37° E: 30.94°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8465	0.0535	0.1829	0.2239	0.9905	0.2003
2	Hermite	0.8424	0.0990	0.1892	0.2298	0.9700	0.2073
3	Linear	0.8312	0.1568	0.2034	0.2419	0.9535	0.2228
9	D. Left	0.5520	0.0179	0.3097	0.3888	1.0008	0.3392

Figure A.9. Wind Analysis of Point SW_5

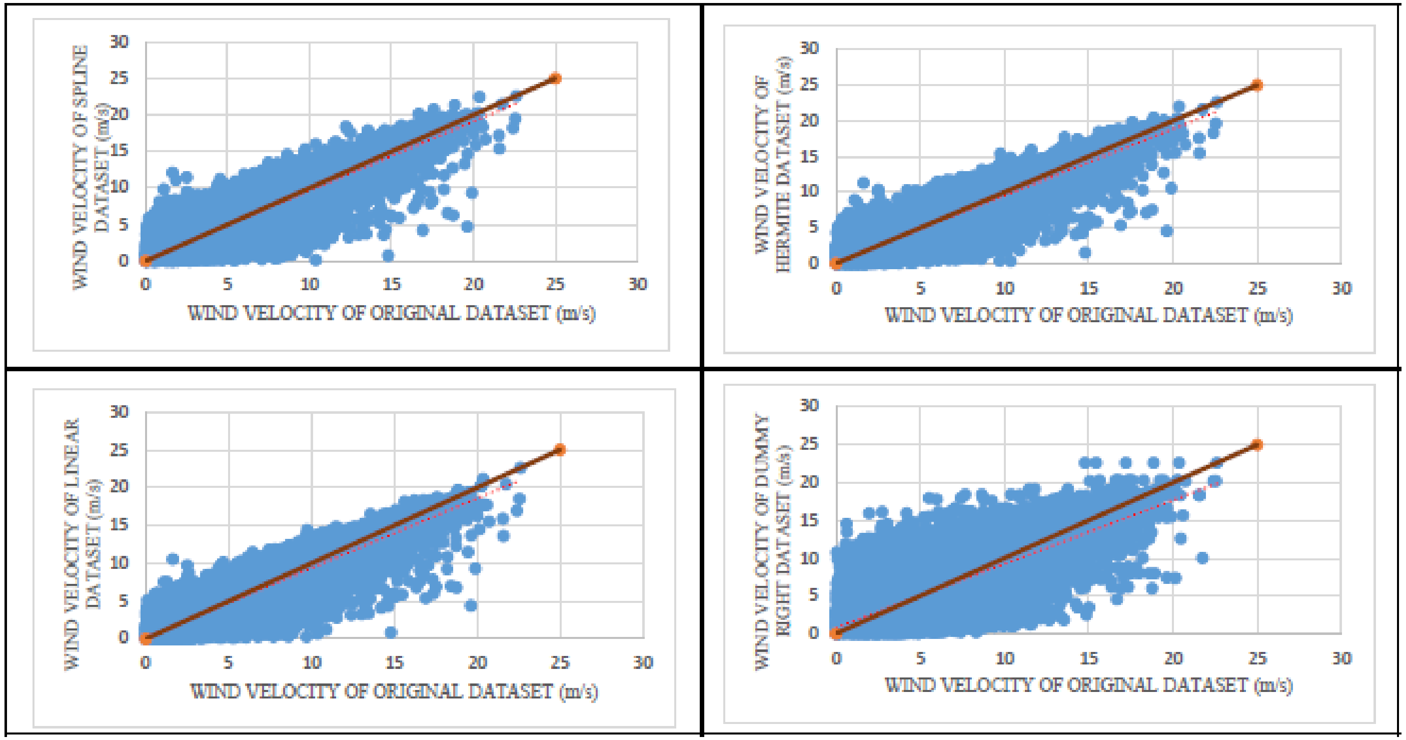
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.87	10.18	5.18	8.84	3.99	7.76	3.49	7.25	-	-	-	-
1-) Spline	6.72	10.30	5.07	8.96	3.93	7.88	3.43	7.36	-2.19	-1.97	-1.72	-1.55
2-) Hermite	6.69	10.27	5.05	8.92	3.90	7.84	3.41	7.33	-2.62	-2.51	-2.37	-2.29
3-) Linear	6.43	10.09	4.89	8.79	3.81	7.76	3.34	7.27	-6.32	-5.59	-4.70	-4.13
9-) Dummy Left	7.44	10.66	5.51	9.18	4.16	7.98	3.58	7.40	8.37	6.50	4.24	2.80



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.93	10.65	8.33	10.91	-	-
1-) Spline	7.98	10.69	8.41	10.97	0.62	0.90
2-) Hermite	8.05	10.69	8.51	10.99	1.51	2.11
3-) Linear	8.07	10.77	8.55	11.09	1.65	2.59
9-) Dummy Left	8.13	11.33	8.57	11.63	2.44	2.82

Figure A.10. Wave Analysis of Point SW_5

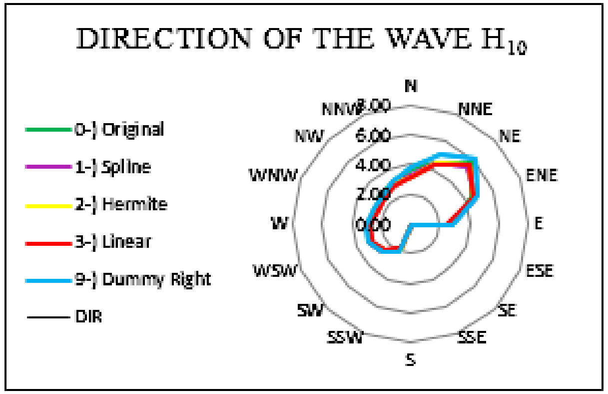
POINT SW_6 - N: 41.68° E: 31.56°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8710	0.0296	0.1751	0.2207	0.9970	0.1918
2	Hermite	0.8687	0.0673	0.1791	0.2247	0.9774	0.1962
3	Linear	0.8603	0.1168	0.1903	0.2336	0.9613	0.2084
9	D. Right	0.6197	-0.0018	0.2997	0.4143	1.0009	0.3283

Figure A.11. Wind Analysis of Point SW_6

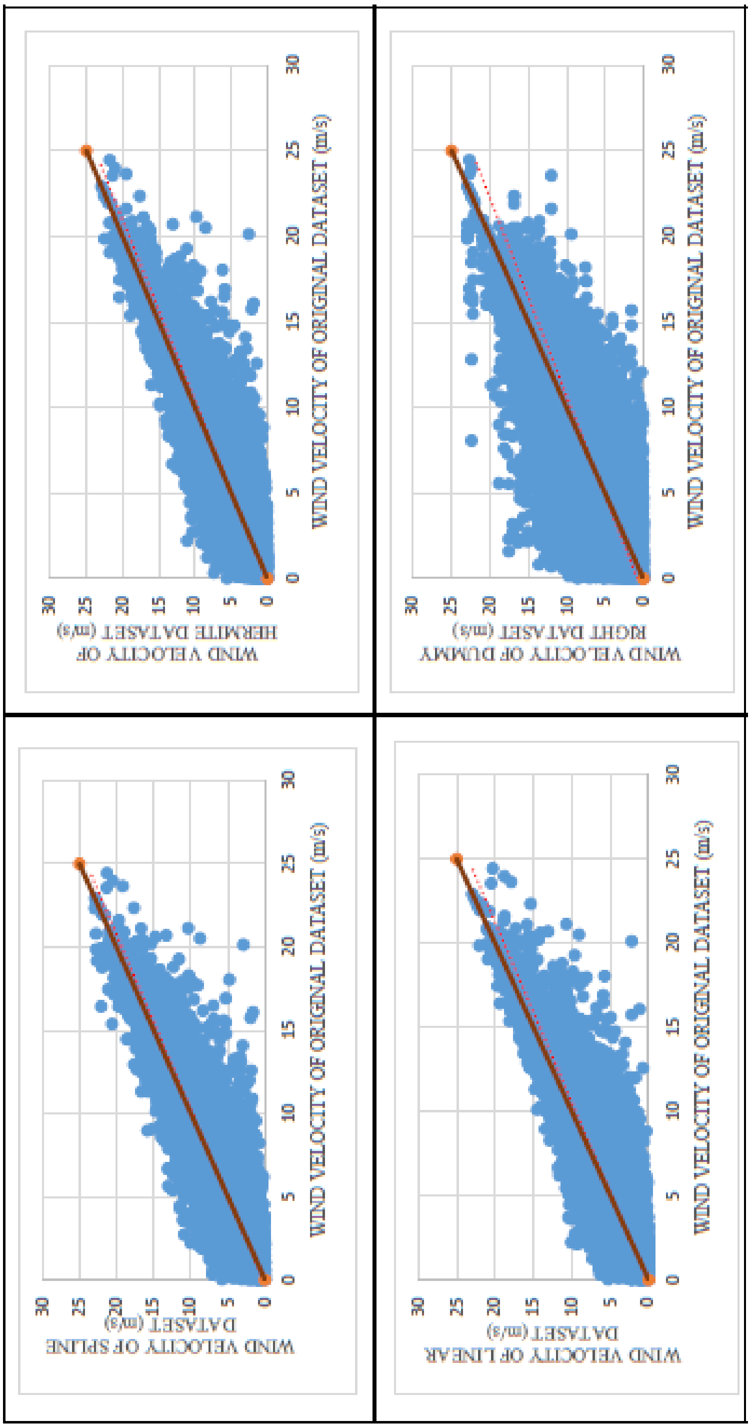
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.74	11.05	5.81	9.57	4.46	8.39	3.88	7.82	-	-	-	-
1-) Spline	7.27	10.68	5.42	9.22	4.12	8.04	3.57	7.48	-6.04	-6.72	-7.54	-8.07
2-) Hermite	7.39	10.77	5.59	9.36	4.33	8.24	3.79	7.71	-4.53	-3.78	-2.88	-2.29
3-) Linear	7.34	10.74	5.55	9.34	4.31	8.23	3.77	7.70	-5.21	-4.41	-3.44	-2.81
9-) Dummy Right	8.27	11.24	6.15	9.69	4.66	8.44	4.02	7.84	6.92	5.84	4.53	3.68



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.74	11.83	9.14	12.10	-	-
1-) Spline	9.14	11.53	9.62	11.83	4.61	5.24
2-) Hermite	9.00	11.38	9.48	11.68	3.06	3.74
3-) Linear	8.87	11.25	9.33	11.54	1.52	2.07
9-) Dummy Right	9.11	12.12	9.56	12.41	4.22	4.57

Figure A.12. Wave Analysis of Point SW_6

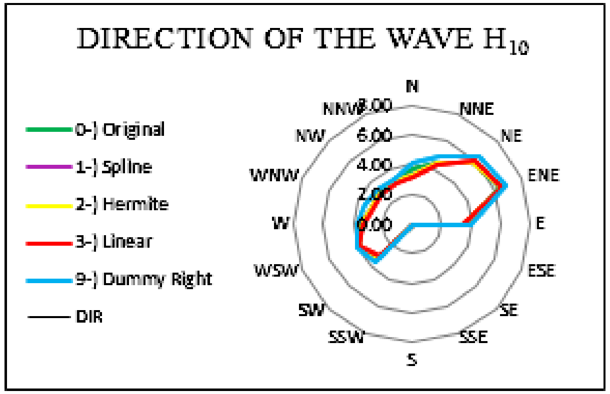
POINT SW_7 - N: 41.99° E: 32.19°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8915	0.0138	0.1618	0.2074	0.9989	0.1772
2	Hermite	0.8912	0.0459	0.1634	0.2081	0.9805	0.1790
3	Linear	0.8854	0.0899	0.1719	0.2132	0.9641	0.1883
9	D. Right	0.6688	-0.0133	0.2824	0.3927	1.0006	0.3094

Figure A.13. Wind Analysis of Point SW_7

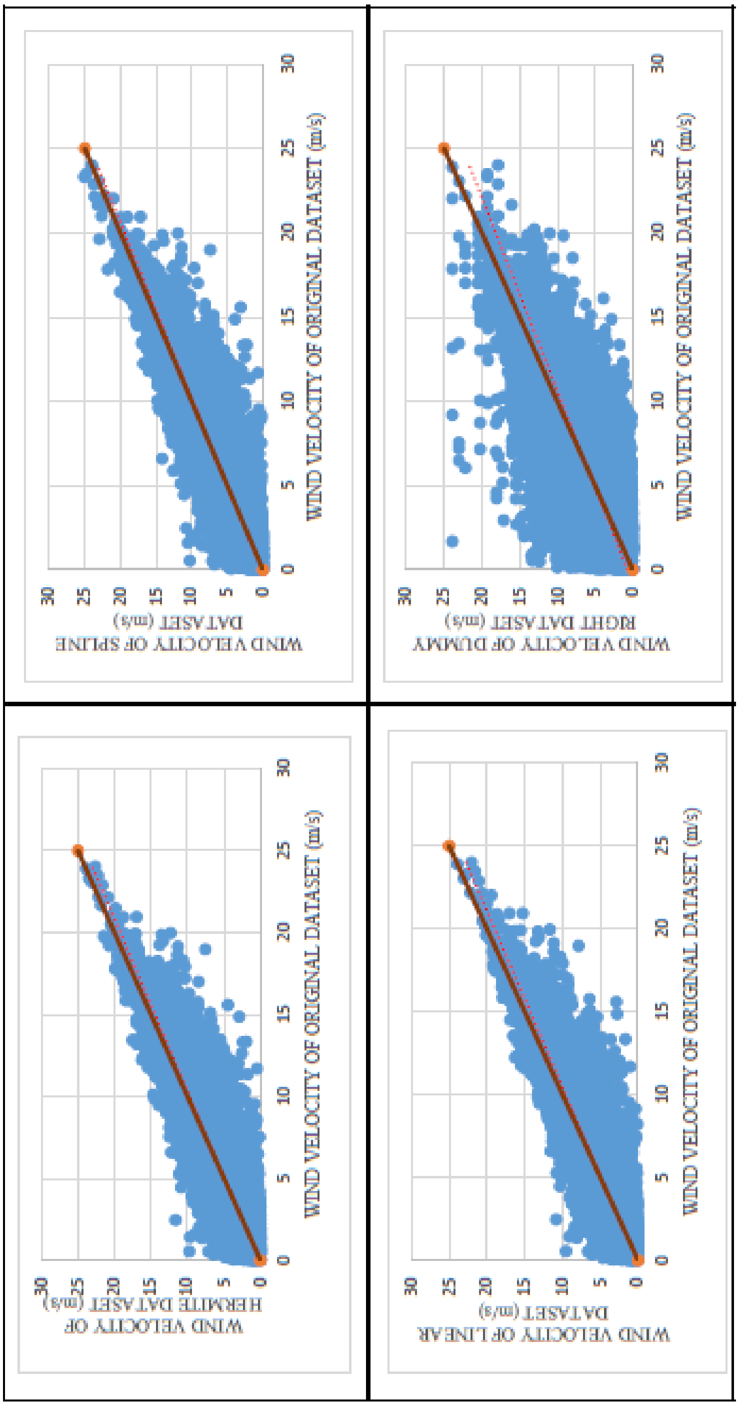
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.83	11.72	6.42	10.00	4.74	8.59	4.01	7.90	-	-	-	-
1-) Spline	9.09	11.88	6.57	10.10	4.80	8.63	4.04	7.92	2.91	2.24	1.37	0.77
2-) Hermite	9.05	11.85	6.53	10.07	4.78	8.61	4.02	7.90	2.46	1.75	0.83	0.19
3-) Linear	9.00	11.83	6.49	10.04	4.74	8.58	3.98	7.87	1.84	1.06	0.06	-0.64
9-) Dummy Right	9.63	12.08	6.92	10.24	5.03	8.73	4.21	7.99	8.98	7.75	6.16	5.06



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	9.50	12.08	9.96	12.36	-	-
1-) Spline	9.67	12.18	10.13	12.47	1.73	1.78
2-) Hermite	9.71	12.42	10.19	12.72	2.14	2.34
3-) Linear	9.60	12.22	10.08	12.53	0.99	1.22
9-) Dummy Right	9.89	12.49	10.39	12.80	4.09	4.38

Figure A.14. Wave Analysis of Point SW_7

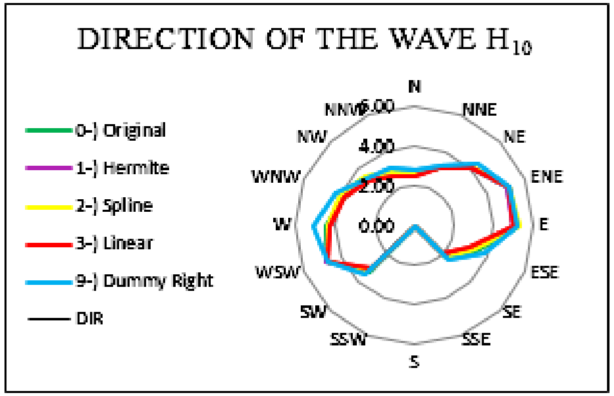
POINT SW_8 - N: 42.31° E: 33.44°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.9058	0.0388	0.1505	0.1859	0.9833	0.1648
2	Spline	0.9055	0.0082	0.1496	0.1866	0.9988	0.1638
3	Linear	0.9017	0.0815	0.1576	0.1889	0.9670	0.1726
9	D. Right	0.6935	-0.0161	0.2694	0.3625	0.9972	0.2951

Figure A.15. Wind Analysis of Point SW_8

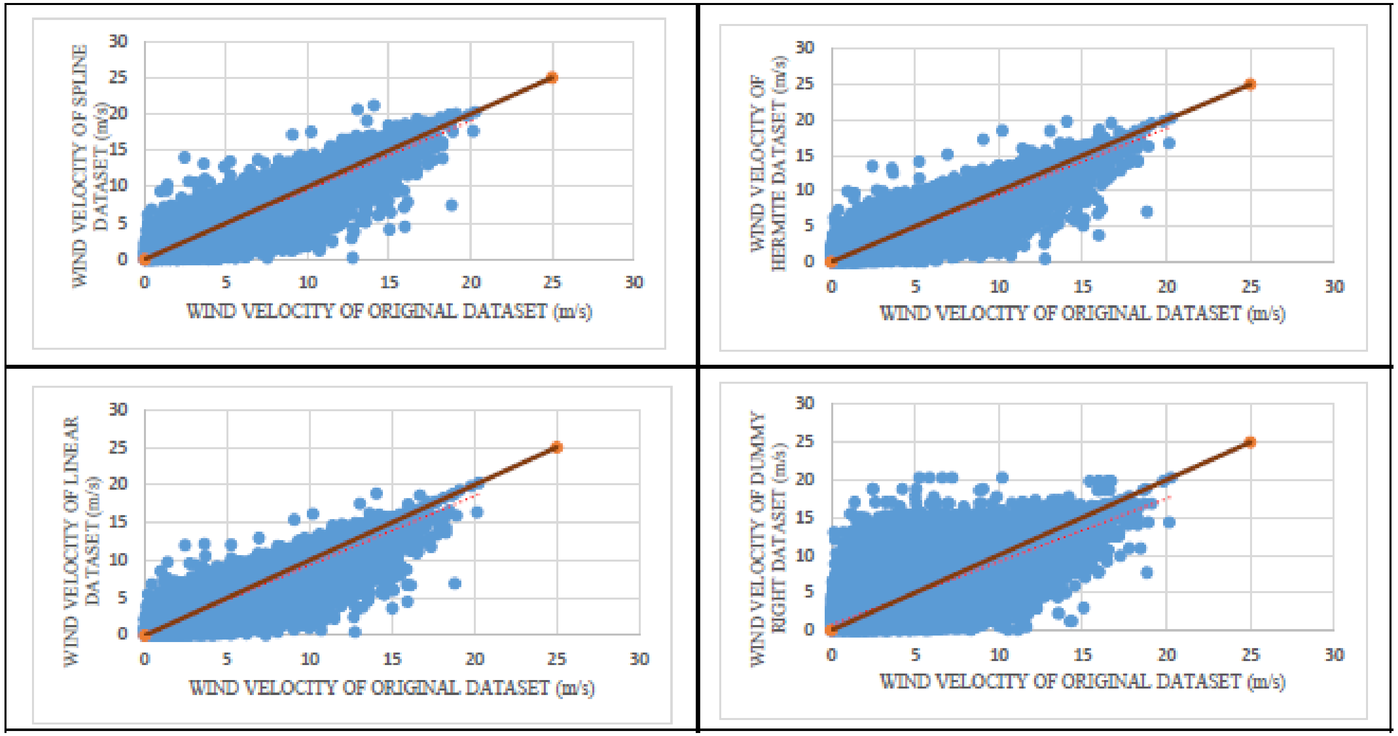
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.98	10.42	5.15	8.95	3.87	7.75	3.35	7.22	-	-	-	-
1-) Hermite	6.72	10.21	5.07	8.87	3.91	7.80	3.42	7.28	-3.76	-1.54	1.26	1.94
2-) Spline	7.34	10.67	5.32	9.09	3.93	7.82	3.43	7.30	5.08	3.42	1.79	2.38
3-) Linear	6.96	10.41	5.20	8.99	3.96	7.85	3.43	7.31	-0.31	0.94	2.52	2.39
9-) Dummy Right	7.17	10.42	5.19	8.86	3.96	7.74	3.45	7.23	2.67	0.76	2.42	3.06



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.81	11.71	9.26	12.01	-	-
1-) Hermite	8.31	12.14	8.63	12.37	-5.67	-6.82
2-) Spline	8.75	11.88	9.14	12.15	-0.65	-1.32
3-) Linear	8.18	12.14	8.50	12.37	-7.11	-8.30
9-) Dummy Right	8.75	11.88	9.15	12.14	-0.59	-1.20

Figure A.16. Wave Analysis of Point SW_8

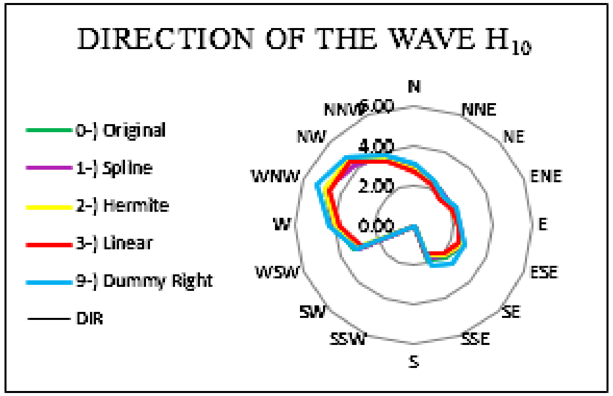
POINT SE_1 - N: 41.99° E: 35.94°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8671	0.0445	0.1796	0.2127	1.0001	0.1967
2	Hermite	0.8682	0.0796	0.1817	0.2132	0.9780	0.1990
3	Linear	0.8662	0.1260	0.1891	0.2156	0.9534	0.2072
9	D. Right	0.5984	0.0166	0.3099	0.3979	1.0121	0.3395

Figure A.17. Wind Analysis of Point SE_1

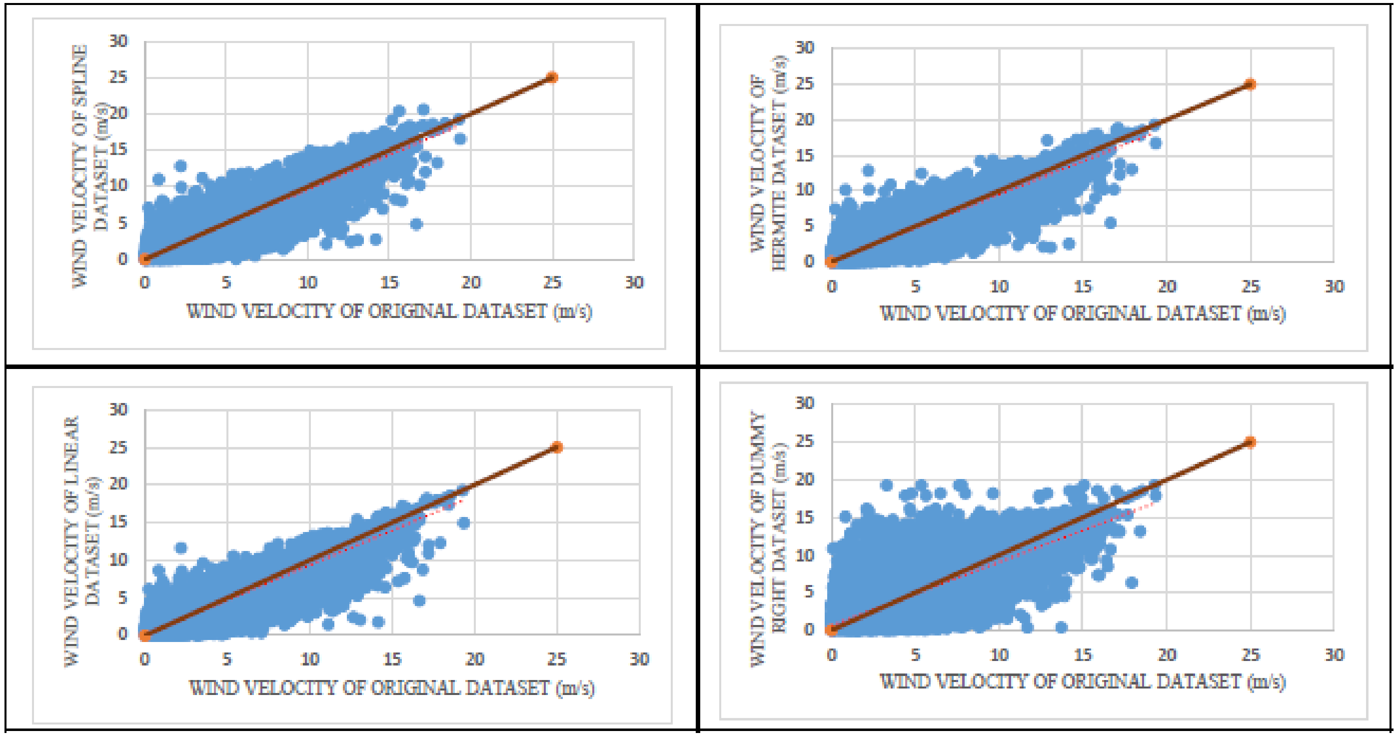
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.49	10.13	4.89	8.79	3.77	7.72	3.29	7.21	-	-	-	-
1-) Spline	6.24	9.92	4.73	8.64	3.68	7.62	3.23	7.14	-3.92	-3.19	-2.32	-1.76
2-) Hermite	6.44	10.08	4.81	8.72	3.71	7.65	3.23	7.14	-0.77	-1.51	-1.69	-1.80
3-) Linear	6.11	9.83	4.63	8.56	3.60	7.55	3.16	7.07	-5.85	-5.19	-4.40	-3.89
9-) Dummy Right	7.15	10.44	5.29	8.98	3.99	7.80	3.43	7.24	10.13	8.21	5.90	4.42



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.56	10.43	7.90	10.66	-	-
1-) Spline	7.61	10.39	7.97	10.64	0.58	0.79
2-) Hermite	7.55	10.30	7.92	10.55	-0.14	0.16
3-) Linear	7.40	10.44	7.76	10.69	-2.13	-1.87
9-) Dummy Right	7.80	11.73	8.17	12.01	3.12	3.41

Figure A.18. Wave Analysis of Point SE_1

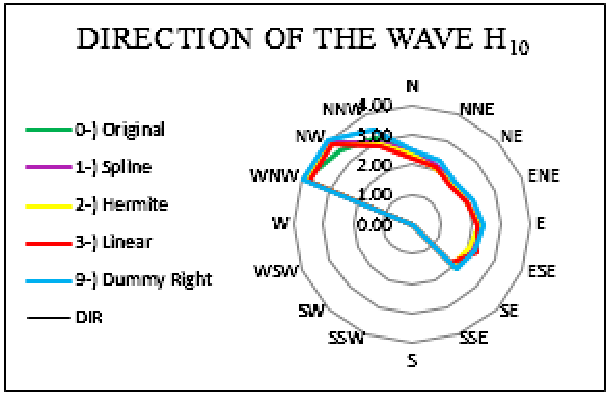
POINT SE_2 - N: 41.99° E: 35.31°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8712	0.0404	0.1782	0.2095	1.0035	0.1952
2	Hermite	0.8725	0.0810	0.1806	0.2114	0.9831	0.1978
3	Linear	0.8701	0.1325	0.1895	0.2163	0.9609	0.2075
9	D. Right	0.6107	0.0107	0.3078	0.3911	1.0103	0.3372

Figure A.19. Wind Analysis of Point SE_2

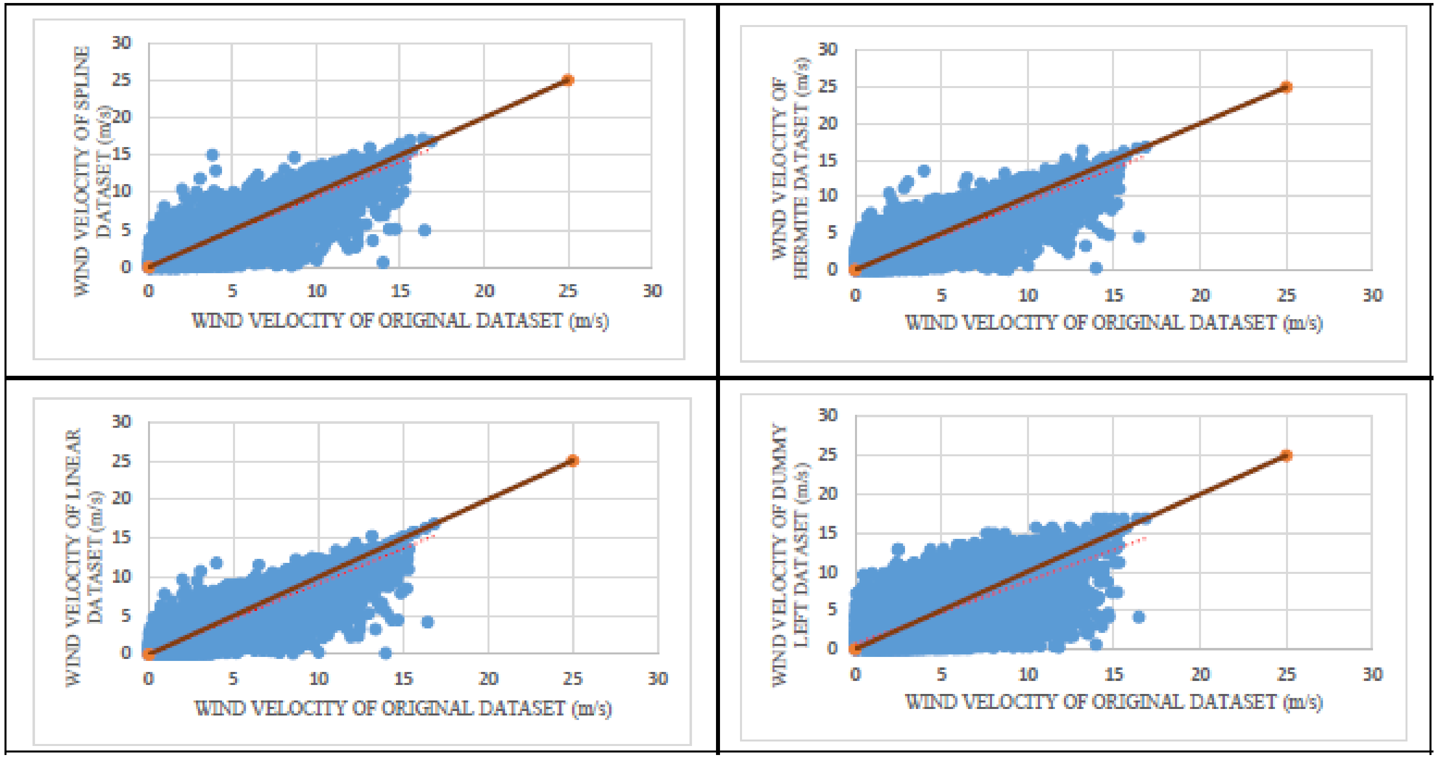
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.25	9.02	3.92	7.79	2.98	6.80	2.58	6.32	-	-	-	-
1-) Spline	5.24	8.99	3.87	7.73	2.96	6.76	2.57	6.30	-0.25	-1.08	-0.72	-0.48
2-) Hermite	5.23	8.99	3.89	7.76	2.95	6.76	2.55	6.28	-0.27	-0.59	-0.99	-1.25
3-) Linear	5.27	9.03	3.85	7.72	2.88	6.68	2.50	6.23	0.35	-1.74	-3.39	-3.09
9-) Dummy Right	5.39	8.96	3.98	7.71	3.02	6.72	2.63	6.26	2.63	1.69	1.37	1.73



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.00	9.87	6.24	10.06	-	-
1-) Spline	6.54	9.86	6.88	10.11	9.00	10.18
2-) Hermite	6.31	9.60	6.62	9.84	5.09	6.00
3-) Linear	6.21	9.75	6.51	9.98	3.43	4.27
9-) Dummy Right	6.42	10.08	6.74	10.32	7.02	8.01

Figure A.20. Wave Analysis of Point SE_2

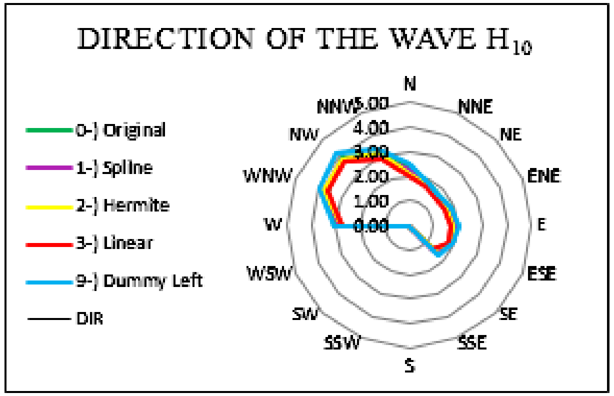
POINT SE_3 - N: 41.68° E: 36.25°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8234	0.0754	0.1973	0.2265	1.0094	0.2162
2	Hermite	0.8227	0.1253	0.2031	0.2308	0.9875	0.2224
3	Linear	0.8188	0.1875	0.2150	0.2369	0.9656	0.2355
9	D. Left	0.4992	0.0413	0.3276	0.4015	1.0323	0.3589

Figure A.21. Wind Analysis of Point SE_3

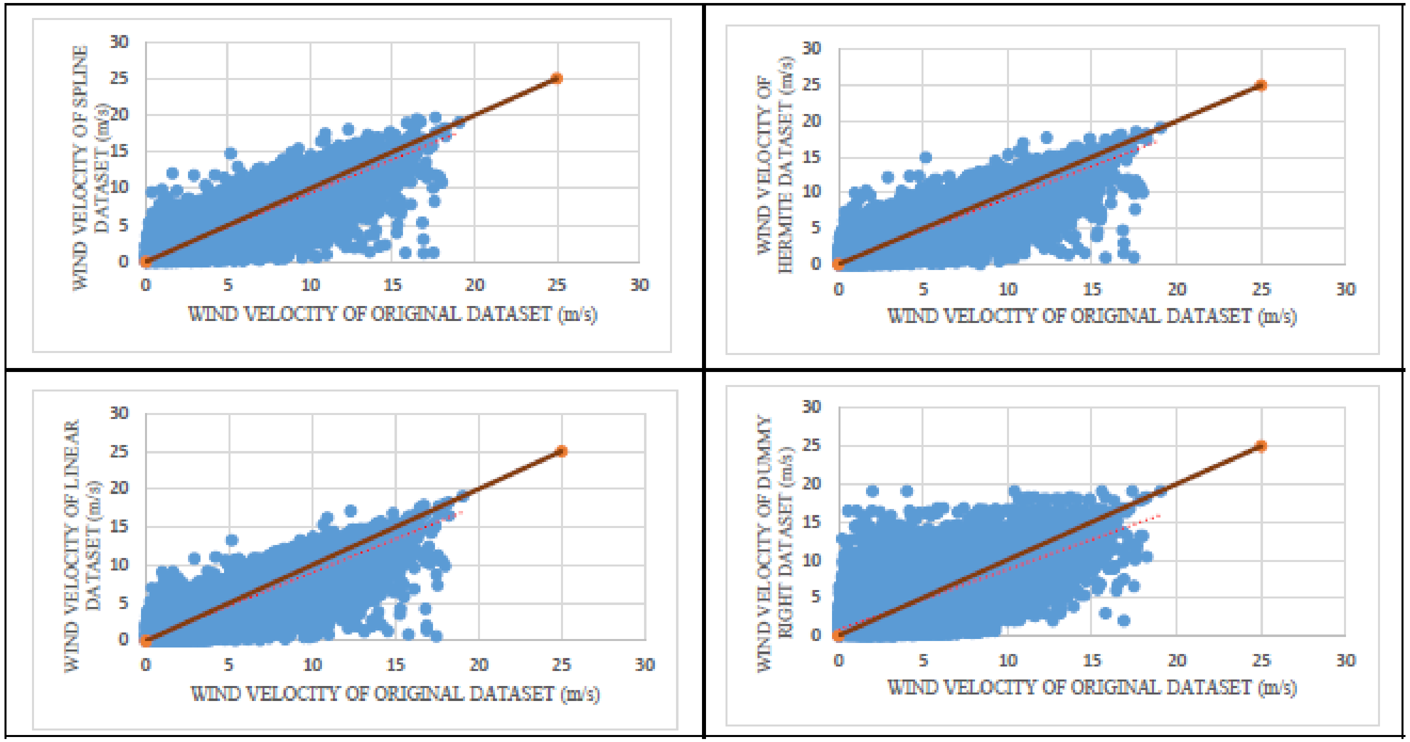
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.33	9.20	3.87	7.85	2.86	6.74	2.42	6.20	-	-	-	-
1-) Spline	5.25	9.11	3.85	7.80	2.87	6.74	2.45	6.23	-1.47	-0.57	0.59	1.40
2-) Hermite	5.22	9.09	3.82	7.78	2.85	6.71	2.42	6.19	-1.95	-1.29	-0.42	0.17
3-) Linear	5.09	8.99	3.74	7.70	2.79	6.66	2.39	6.15	-4.51	-3.55	-2.30	-1.44
9-) Dummy Left	5.80	9.39	4.18	7.97	3.04	6.80	2.55	6.23	8.89	7.80	6.37	5.39



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.21	9.69	6.53	9.94	-	-
1-) Spline	6.36	9.86	6.73	10.13	2.52	3.02
2-) Hermite	6.34	9.73	6.71	10.01	2.14	2.76
3-) Linear	6.29	9.81	6.66	10.09	1.31	1.99
9-) Dummy Left	6.37	10.85	6.72	11.14	2.69	3.01

Figure A.22. Wave Analysis of Point SE_3

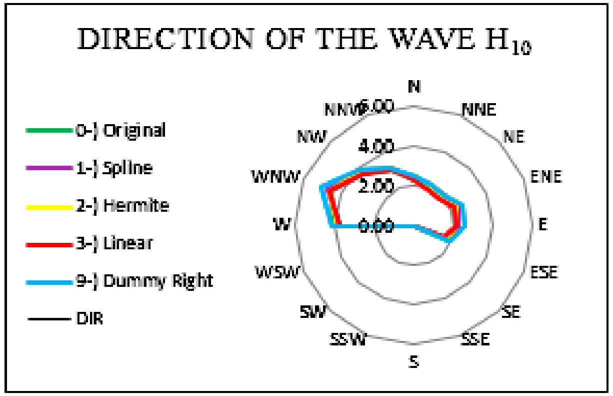
POINT SE_4 - N: 41.37° E: 37.50°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.8072	0.0617	0.2228	0.2783	0.9941	0.2440
2	Hermite	0.8064	0.1065	0.2275	0.2812	0.9620	0.2492
3	Linear	0.8022	0.1620	0.2378	0.2852	0.9315	0.2605
9	D. Right	0.4910	0.0236	0.3586	0.4862	1.0077	0.3929

Figure A.23. Wind Analysis of Point SE_4

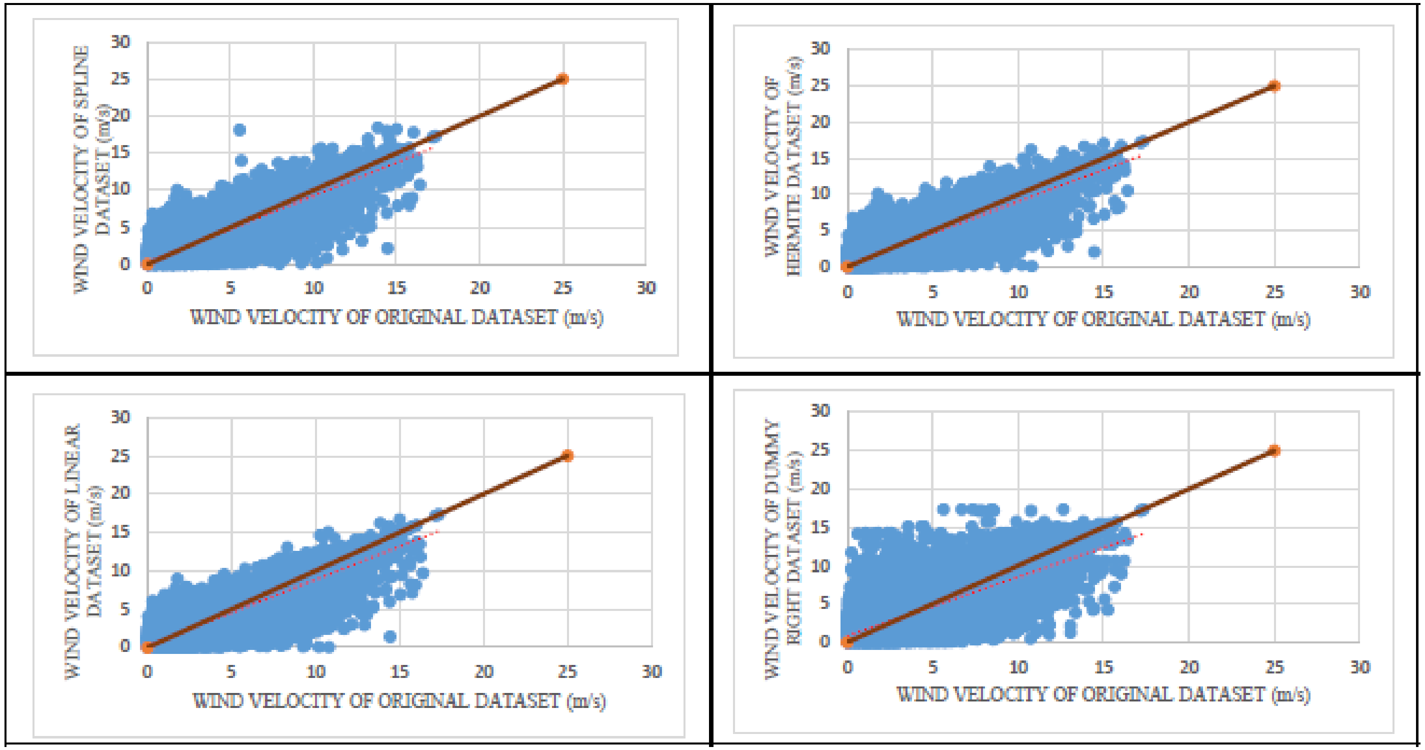
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.06	9.78	4.51	8.44	3.43	7.35	2.96	6.83	-	-	-	-
1-) Spline	6.37	10.01	4.71	8.60	3.54	7.46	3.04	6.92	5.11	4.35	3.40	2.79
2-) Hermite	6.29	9.95	4.65	8.55	3.50	7.42	3.01	6.87	3.78	3.08	2.20	1.63
3-) Linear	6.18	9.87	4.57	8.48	3.44	7.36	2.95	6.82	1.98	1.21	0.27	-0.35
9-) Dummy Right	7.00	10.26	5.10	8.75	3.77	7.53	3.20	6.93	15.44	13.01	10.00	8.03



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.03	10.17	7.39	10.43	-	-
1-) Spline	7.27	10.72	7.66	11.00	3.53	3.63
2-) Hermite	7.21	10.70	7.60	10.99	2.61	2.81
3-) Linear	7.12	10.41	7.51	10.69	1.33	1.66
9-) Dummy Right	7.54	11.68	7.96	12.01	7.29	7.74

Figure A.24. Wave Analysis of Point SE_4

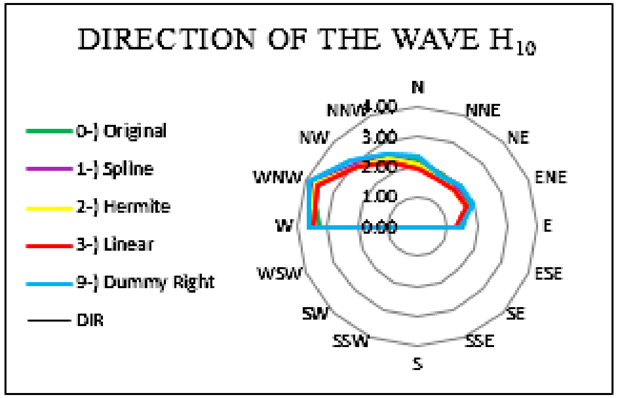
POINT SE_5 - N: 41.06° E: 38.13°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.7873	0.0688	0.2301	0.3066	0.9783	0.2521
2	Hermite	0.7829	0.1217	0.2377	0.3098	0.9410	0.2604
3	Linear	0.7801	0.1830	0.2484	0.3108	0.9151	0.2721
9	D. Right	0.4775	0.0245	0.3570	0.5123	0.9697	0.3910

Figure A.25. Wind Analysis of Point SE_5

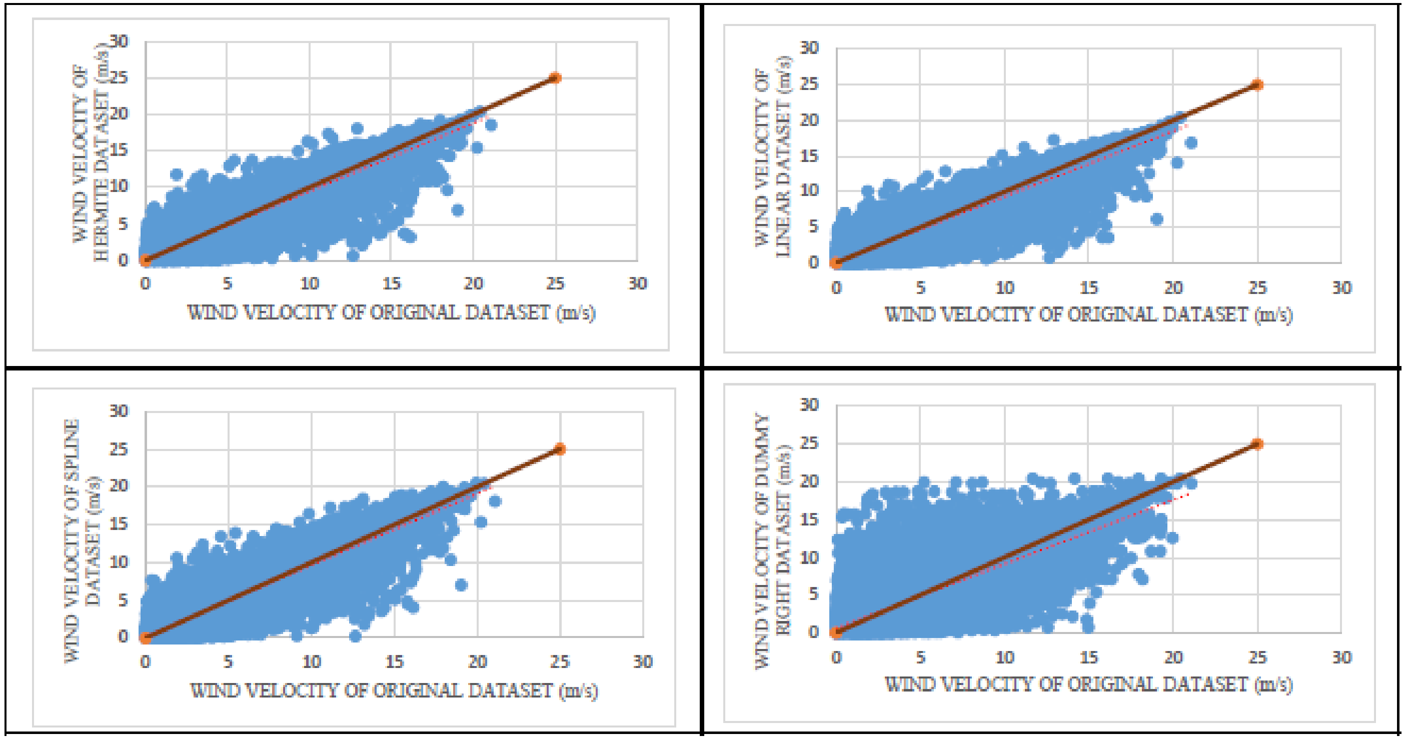
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.28	9.16	3.79	7.76	2.75	6.61	2.30	6.05	-	-	-	-
1-) Spline	5.28	9.10	3.81	7.73	2.81	6.64	2.38	6.11	-0.05	0.45	2.12	3.31
2-) Hermite	5.21	9.02	3.71	7.61	2.74	6.54	2.32	6.02	-1.33	-2.28	-0.51	0.74
3-) Linear	5.15	9.00	3.64	7.56	2.69	6.50	2.28	5.98	-2.42	-4.12	-2.38	-1.14
9-) Dummy Right	5.45	9.02	3.94	7.67	2.88	6.56	2.42	6.02	3.18	3.81	4.65	5.25



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.83	9.90	6.16	10.17	-	-
1-) Spline	6.60	10.39	7.04	10.73	13.22	14.36
2-) Hermite	6.43	10.28	6.85	10.61	10.25	11.19
3-) Linear	6.26	9.77	6.67	10.08	7.38	8.33
9-) Dummy Right	6.52	10.83	6.94	11.17	11.94	12.69

Figure A.26. Wave Analysis of Point SE_5

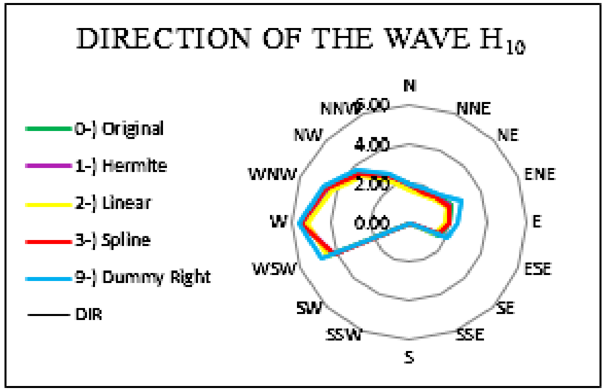
POINT SE_6 - N: 41.37° E: 39.38°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.8553	0.0629	0.2177	0.2807	0.9898	0.2385
2	Linear	0.8540	0.1064	0.2241	0.2795	0.9614	0.2454
3	Spline	0.8530	0.0282	0.2171	0.2850	1.0129	0.2379
9	D. Right	0.5972	0.0024	0.3585	0.4940	1.0301	0.3927

Figure A.27. Wind Analysis of Point SE_6

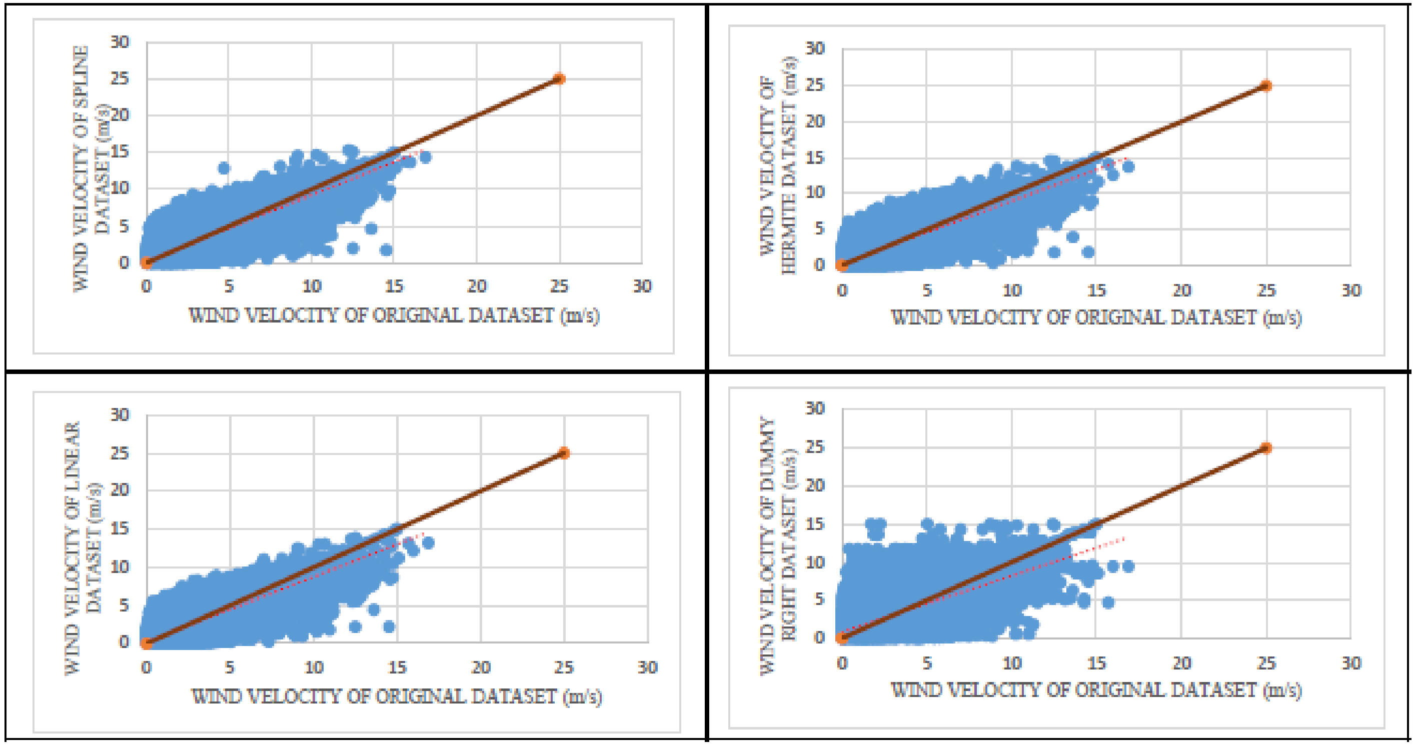
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.19	10.60	5.41	9.19	4.16	8.06	3.62	7.52	-	-	-	-
1-) Hermite	7.21	10.60	5.42	9.19	4.16	8.05	3.62	7.51	0.25	0.18	0.10	0.05
2-) Linear	6.93	10.40	5.24	9.05	4.06	7.97	3.56	7.45	-3.64	-3.03	-2.30	-1.82
3-) Spline	7.31	10.67	5.48	9.25	4.21	8.10	3.66	7.55	1.61	1.43	1.21	1.06
9-) Dummy Right	7.42	10.55	5.58	9.15	4.30	8.03	3.75	7.50	3.18	3.28	3.41	3.49



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.40	10.88	8.85	11.16	-	-
1-) Hermite	8.48	10.89	8.94	11.18	0.92	1.00
2-) Linear	8.41	10.78	8.87	11.07	0.05	0.26
3-) Spline	8.45	11.00	8.89	11.28	0.60	0.47
9-) Dummy Right	8.45	12.01	8.87	12.31	0.54	0.24

Figure A.28. Wave Analysis of Point SE_6

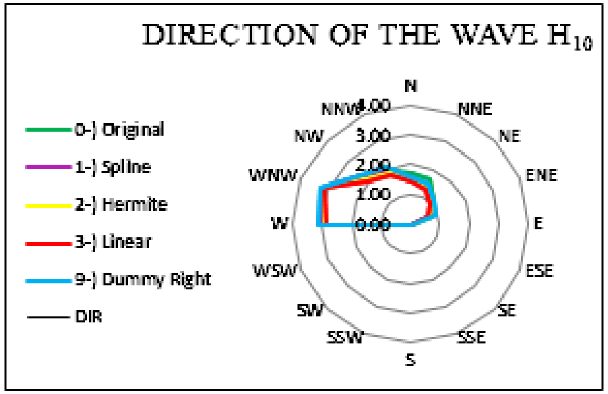
POINT SE_7 - N: 41.06° E: 40.00°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.7675	0.0653	0.2463	0.3392	0.9959	0.2698
2	Hermite	0.7668	0.1236	0.2523	0.3402	0.9453	0.2764
3	Linear	0.7632	0.1876	0.2640	0.3414	0.9124	0.2892
9	D. Right	0.4083	0.0143	0.3895	0.5596	0.9661	0.4266

Figure A.29. Wind Analysis of Point SE_7

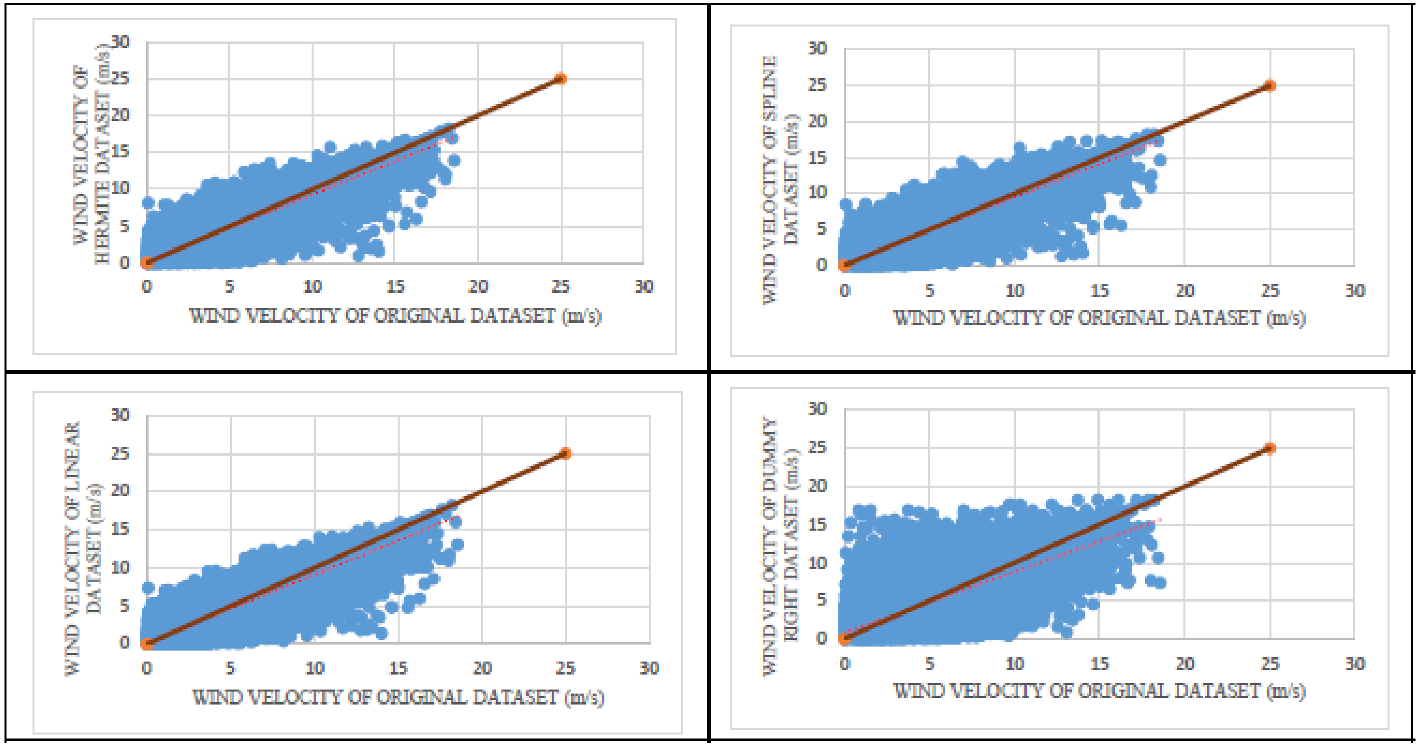
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	4.45	8.45	3.14	7.10	2.23	5.98	1.83	5.42	-	-	-	-
1-) Spline	4.54	8.47	3.20	7.11	2.26	5.98	1.86	5.42	1.88	1.73	1.52	1.37
2-) Hermite	4.47	8.39	3.14	7.04	2.22	5.91	1.82	5.35	0.40	-0.01	-0.57	-0.99
3-) Linear	4.49	8.43	3.12	7.02	2.16	5.85	1.75	5.26	0.91	-0.70	-2.95	-4.60
9-) Dummy Right	4.65	8.30	3.28	6.97	2.33	5.87	1.92	5.33	4.41	4.42	4.44	4.45



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.15	8.98	5.47	9.25	-	-
1-) Spline	5.13	9.81	5.42	10.09	-0.40	-0.81
2-) Hermite	5.11	9.63	5.42	9.91	-0.72	-0.98
3-) Linear	5.33	9.58	5.73	9.93	3.54	4.82
9-) Dummy Right	5.44	9.95	5.77	10.25	5.56	5.52

Figure A.30. Wave Analysis of Point SE_7

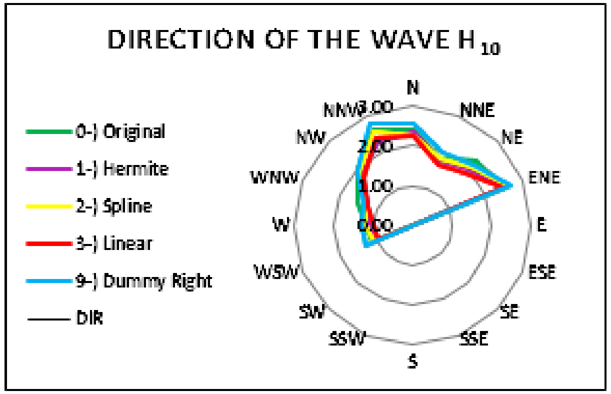
POINT SE_8 - N: 41.37° E: 40.63°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.8066	0.0931	0.2287	0.3002	0.9845	0.2505
2	Spline	0.8029	0.0504	0.2273	0.3020	1.0166	0.2490
3	Linear	0.8046	0.1445	0.2366	0.3012	0.9553	0.2592
9	D. Right	0.4914	0.0139	0.3629	0.4981	1.0223	0.3975

Figure A.31. Wind Analysis of Point SE_8

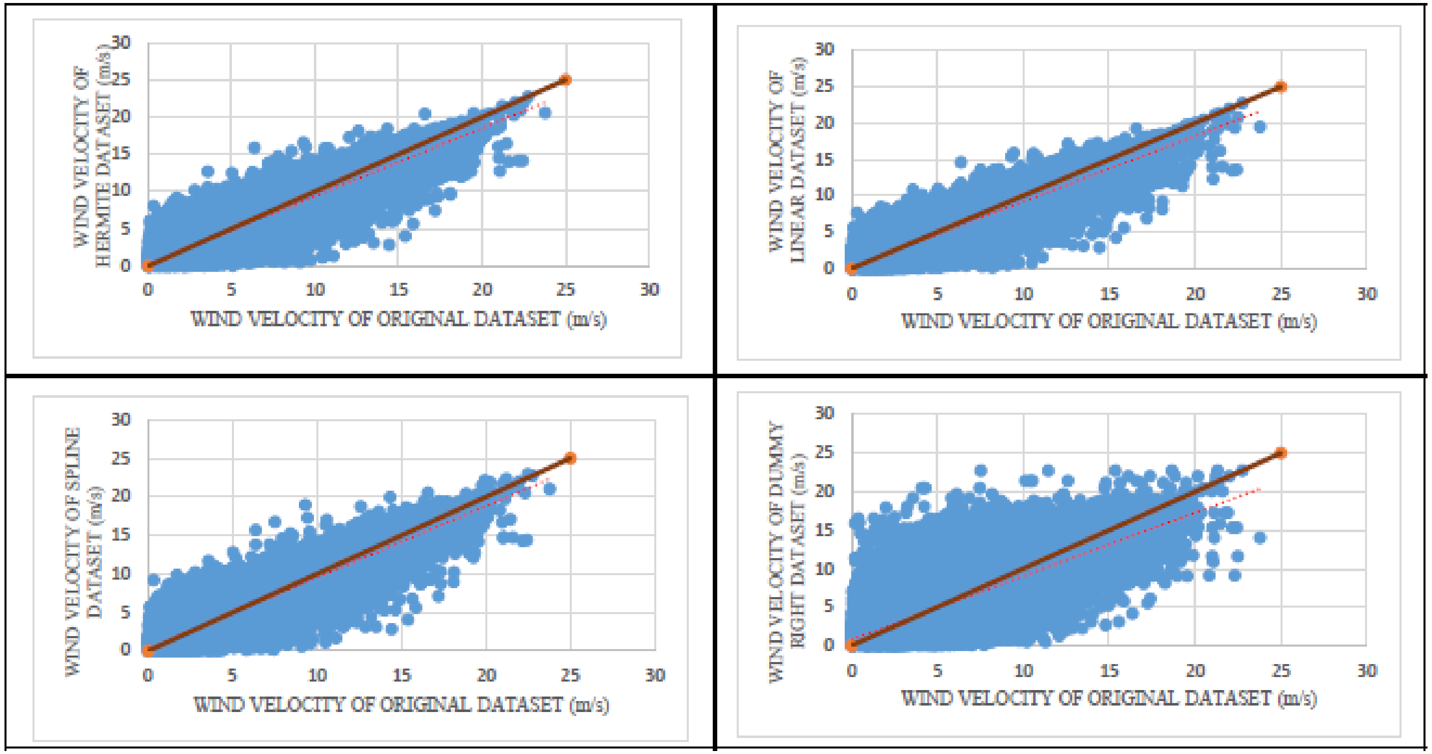
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	3.46	7.22	2.61	6.27	2.02	5.51	1.76	5.15	-	-	-	-
1-) Hermite	3.32	7.03	2.48	6.08	1.90	5.33	1.65	4.97	-4.07	-4.88	-5.62	-6.10
2-) Spline	3.52	7.24	2.61	6.23	1.97	5.42	1.70	5.03	1.76	-0.04	-2.20	-3.58
3-) Linear	3.29	7.00	2.46	6.06	1.89	5.30	1.64	4.94	-5.00	-5.65	-6.42	-6.91
9-) Dummy Right	3.85	7.47	2.80	6.36	2.06	5.46	1.74	5.02	11.24	7.07	2.07	-1.13



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	4.34	9.00	4.52	9.19	-	-
1-) Hermite	3.94	9.68	4.09	9.87	-9.20	-9.63
2-) Spline	4.23	9.12	4.43	9.32	-2.35	-2.06
3-) Linear	3.97	9.12	4.14	9.30	-8.40	-8.49
9-) Dummy Right	4.12	9.54	4.29	9.73	-4.89	-5.03

Figure A.32. Wave Analysis of Point SE_8

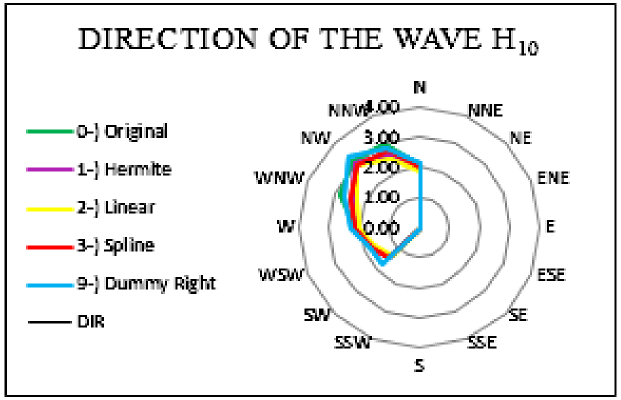
POINT SE_9 - N: 41.68° E: 41.25°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.8402	0.0759	0.2194	0.2982	0.9664	0.2403
2	Linear	0.8403	0.1199	0.2249	0.2961	0.9394	0.2464
3	Spline	0.8341	0.0407	0.2207	0.3028	0.9944	0.2418
9	D. Right	0.5725	0.0112	0.3525	0.4878	1.0027	0.3862

Figure A.33. Wind Analysis of Point SE_9

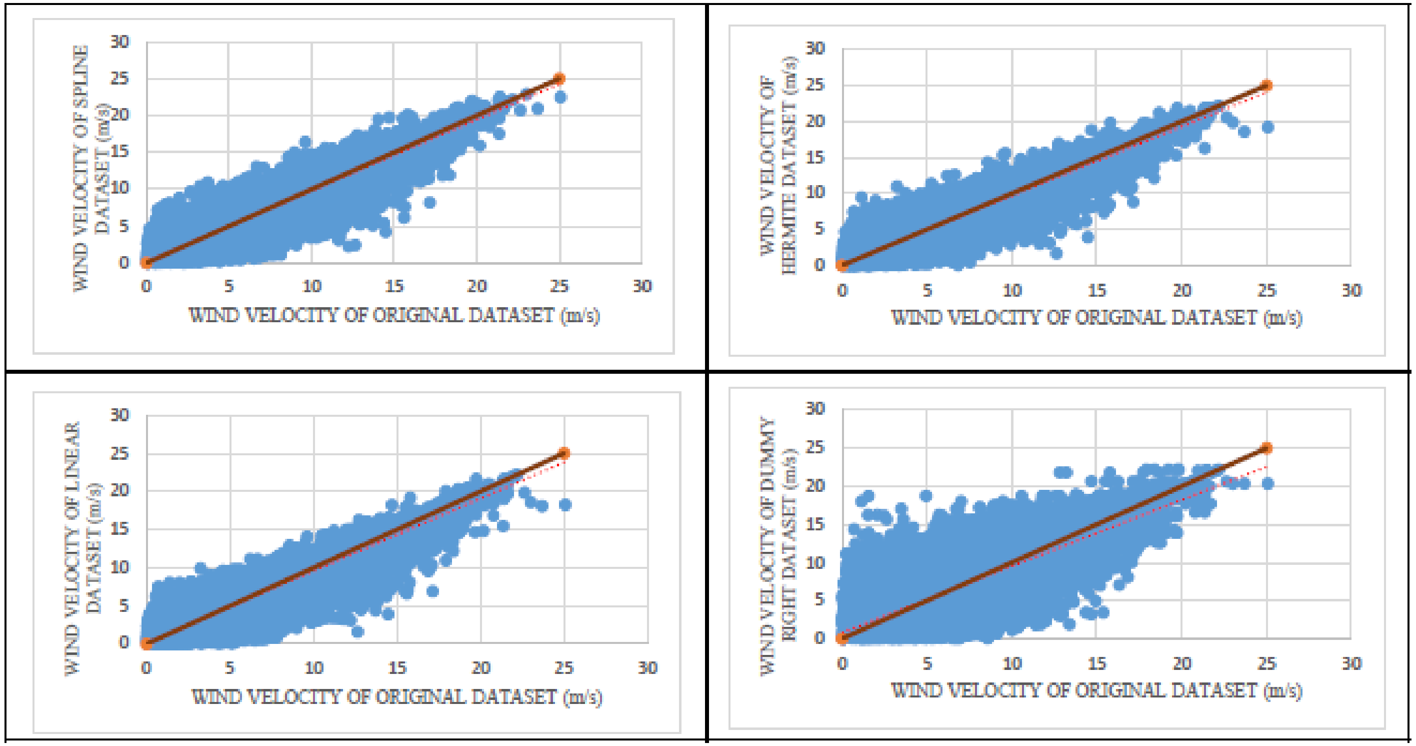
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	4.16	8.09	3.12	7.01	2.42	6.17	2.12	5.78	-	-	-	-
1-) Hermite	4.09	7.98	3.01	6.84	2.25	5.92	1.93	5.47	-1.59	-3.48	-6.98	-9.20
2-) Linear	4.00	7.90	2.93	6.76	2.19	5.84	1.87	5.40	-3.83	-5.94	-9.68	-12.04
3-) Spline	3.90	7.79	2.92	6.74	2.23	5.90	1.94	5.49	-6.20	-6.35	-7.73	-8.61
9-) Dummy Right	4.61	8.30	3.34	7.07	2.45	6.05	2.07	5.56	10.82	7.01	1.08	-2.68



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	4.87	9.52	5.11	9.76	-	-
1-) Hermite	4.89	8.81	5.20	9.09	0.40	1.91
2-) Linear	4.50	8.77	4.73	9.00	-7.60	-7.33
3-) Spline	4.66	8.95	4.90	9.18	-4.24	-4.14
9-) Dummy Right	4.90	10.91	5.15	11.19	0.64	0.86

Figure A.34. Wave Analysis of Point SE_9

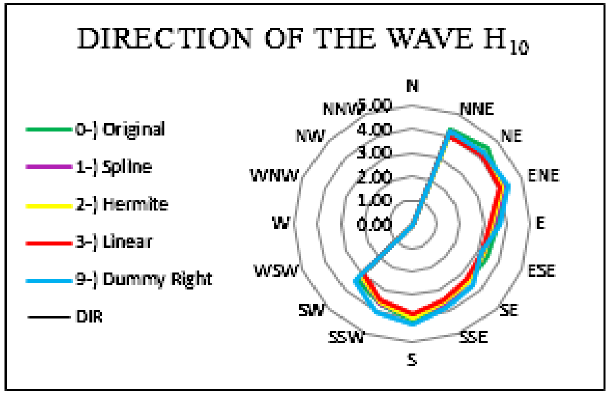
POINT N_1 - N: 44.18° E: 29.06°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.9120	0.0236	0.1287	0.1481	1.0030	0.1410
2	Hermite	0.9125	0.0552	0.1302	0.1510	0.9878	0.1426
3	Linear	0.9084	0.0980	0.1376	0.1564	0.9761	0.1508
9	D. Right	0.6847	0.0039	0.2429	0.3244	1.0023	0.2661

Figure A.35. Wind Analysis of Point N_1

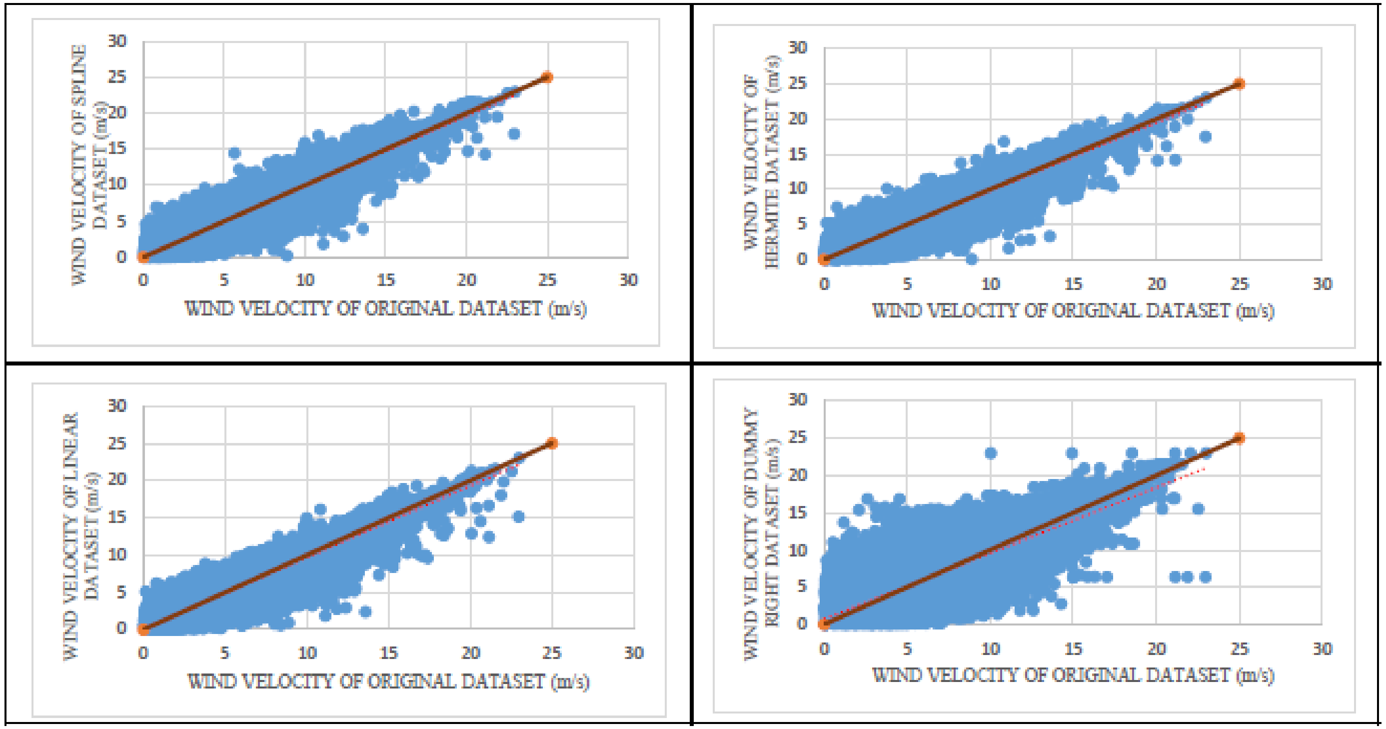
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.18	9.62	4.46	8.17	3.25	6.97	2.73	6.39	-	-	-	-
1-) Spline	6.23	9.65	4.21	7.93	3.13	6.84	2.68	6.33	0.76	-5.60	-3.81	-2.02
2-) Hermite	6.01	9.49	4.24	7.96	3.13	6.85	2.66	6.31	-2.80	-4.98	-3.65	-2.71
3-) Linear	5.89	9.40	4.14	7.88	3.07	6.79	2.62	6.27	-4.75	-7.18	-5.49	-4.30
9-) Dummy Right	6.56	9.84	4.33	8.00	3.15	6.82	2.68	6.29	6.07	-2.80	-3.24	-2.07



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.83	11.01	8.25	11.31	-	-
1-) Spline	7.35	11.21	7.67	11.46	-6.10	-6.94
2-) Hermite	7.28	11.45	7.61	11.70	-6.94	-7.75
3-) Linear	7.25	11.43	7.57	11.68	-7.40	-8.20
9-) Dummy Right	7.28	11.19	7.57	11.41	-7.04	-8.18

Figure A.36. Wave Analysis of Point N_1

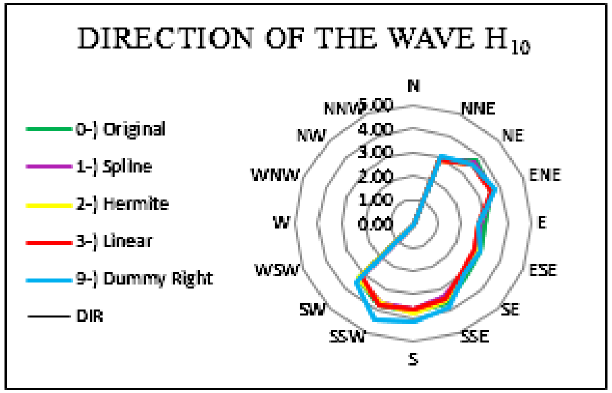
POINT N_2 - N: 45.43° E: 30.00°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Spline	0.9105	0.0071	0.1263	0.1461	1.0225	0.1383
2	Hermite	0.9118	0.0389	0.1264	0.1478	1.0094	0.1385
3	Linear	0.9080	0.0822	0.1326	0.1530	0.9983	0.1453
9	D. Right	0.6842	-0.0120	0.2372	0.3119	1.0231	0.2599

Figure A.37. Wind Analysis of Point N_2

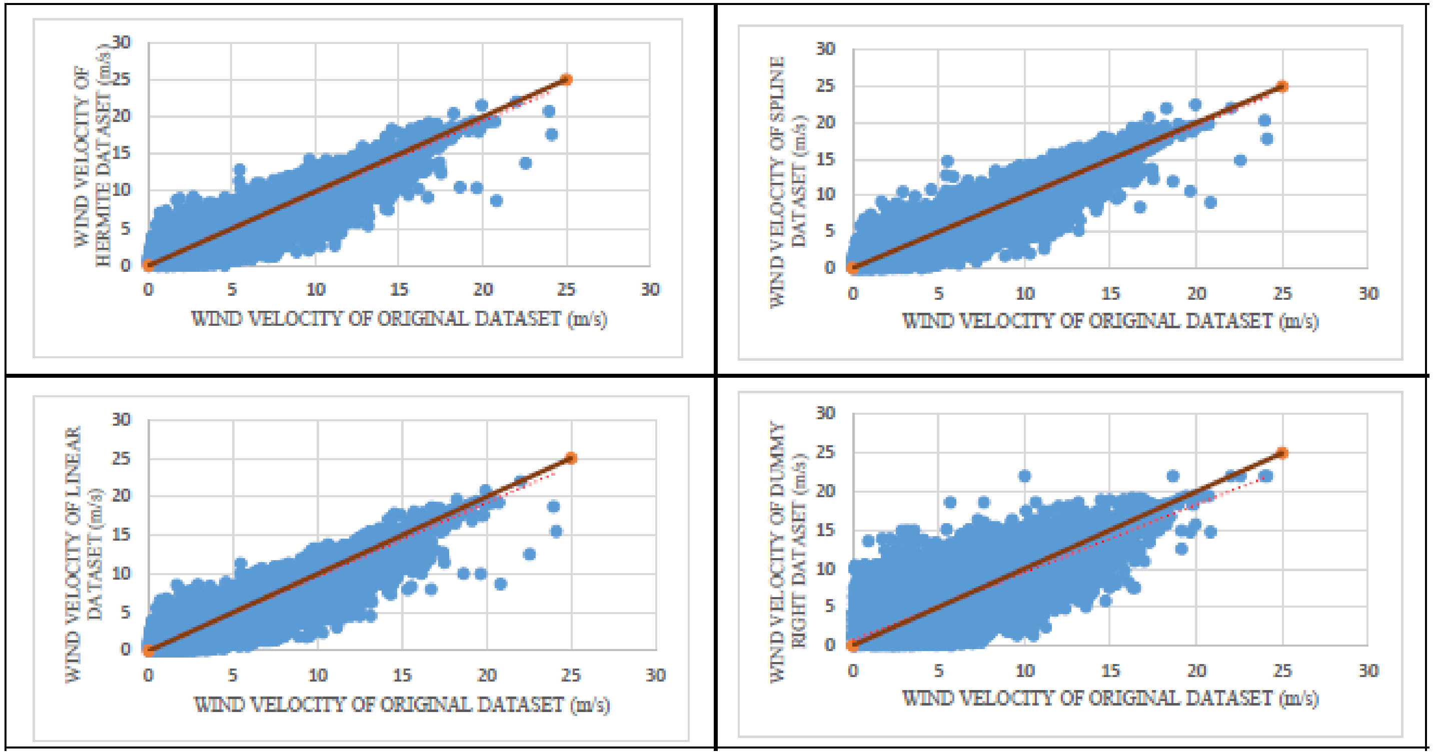
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.37	9.02	3.77	7.56	2.85	6.57	2.46	6.10	-	-	-	-
1-) Spline	5.32	8.96	3.67	7.44	2.79	6.49	2.42	6.04	-1.03	-2.78	-2.12	-1.49
2-) Hermite	5.27	8.92	3.77	7.55	2.77	6.47	2.38	6.00	-2.00	0.01	-2.79	-2.97
3-) Linear	5.17	8.84	3.77	7.55	2.79	6.49	2.37	5.98	-3.74	-0.02	-2.18	-3.68
9-) Dummy Right	6.12	9.53	4.35	8.04	3.12	6.80	2.59	6.20	13.92	15.50	9.44	5.33



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.79	10.41	7.11	10.65	-	-
1-) Spline	6.80	10.87	7.14	11.13	0.25	0.44
2-) Hermite	6.73	10.80	7.06	11.07	-0.83	-0.60
3-) Linear	6.63	10.76	6.97	11.03	-2.30	-1.97
9-) Dummy Right	6.66	9.53	6.99	9.76	-1.82	-1.64

Figure A.38. Wave Analysis of Point N_2

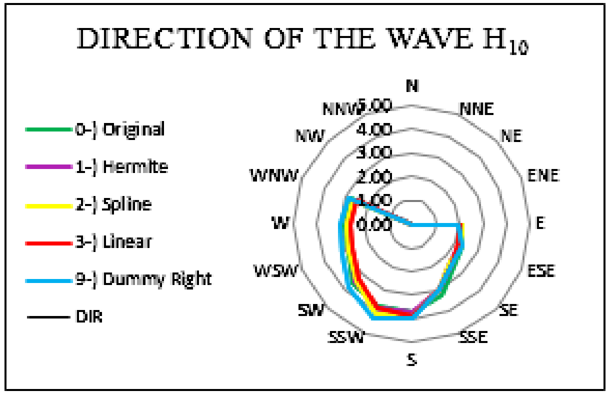
POINT N_3 - N: 46.37° E: 31.25°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.9102	0.0443	0.1282	0.1502	1.0047	0.1404
2	Spline	0.9070	0.0161	0.1292	0.1498	1.0224	0.1415
3	Linear	0.9065	0.0852	0.1343	0.1552	0.9898	0.1472
9	D. Right	0.6836	-0.0032	0.2380	0.3157	1.0237	0.2607

Figure A.39. Wind Analysis of Point N_3

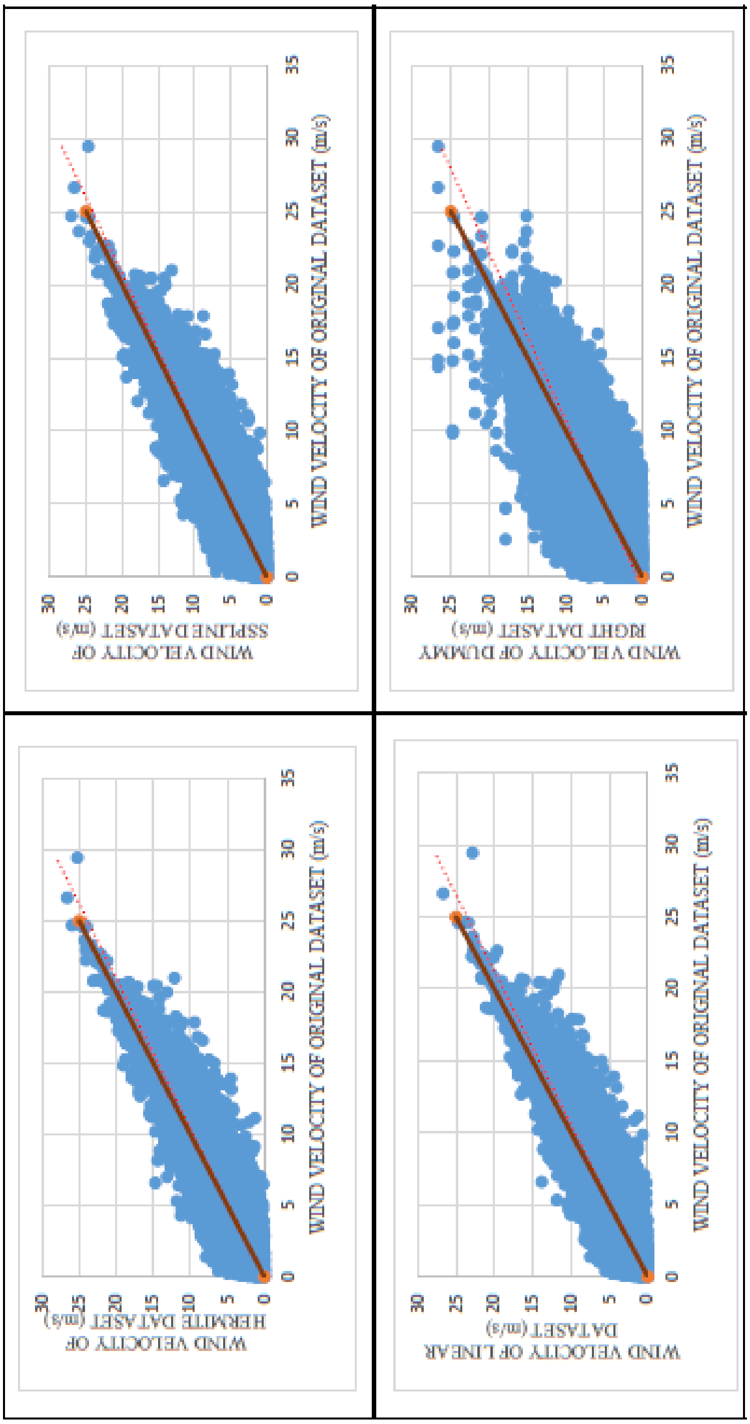
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	5.08	8.90	3.75	7.65	2.84	6.66	2.45	6.18	-	-	-	-
1-) Hermite	5.29	9.07	3.85	7.75	2.85	6.66	2.42	6.14	4.13	2.64	0.32	-1.22
2-) Spline	5.67	9.40	4.07	7.96	2.95	6.77	2.46	6.19	11.71	8.36	3.68	0.58
3-) Linear	5.59	9.33	3.87	7.76	2.80	6.60	2.36	6.06	10.05	3.07	-1.47	-3.57
9-) Dummy Right	6.05	9.59	4.31	8.09	3.09	6.85	2.57	6.25	19.22	14.86	8.89	4.95



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.20	10.76	6.46	10.99	-	-
1-) Hermite	6.35	10.19	6.66	10.43	2.49	3.02
2-) Spline	6.33	9.86	6.61	10.08	2.12	2.32
3-) Linear	6.31	10.06	6.61	10.30	1.81	2.34
9-) Dummy Right	6.63	11.45	6.96	11.73	7.02	7.64

Figure A.40. Wave Analysis of Point N_3

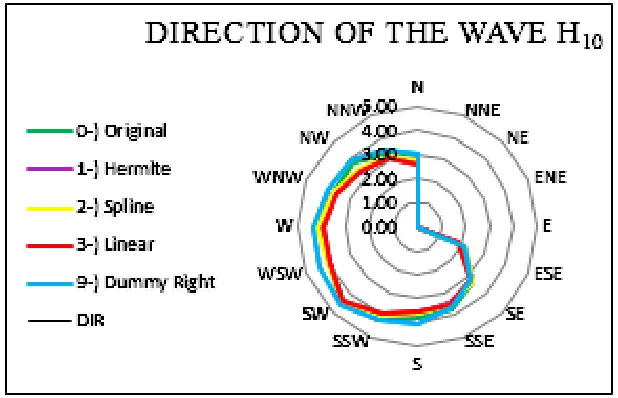
POINT N_4 - N: 44.80° E: 33.13°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.8974	0.0780	0.1503	0.1769	0.9868	0.1646
2	Spline	0.8934	0.0496	0.1506	0.1774	1.0046	0.1649
3	Linear	0.8974	0.1175	0.1555	0.1789	0.9648	0.1704
9	D. Right	0.6624	0.0298	0.2652	0.3577	1.0207	0.2905

Figure A.41. Wind Analysis of Point N_4

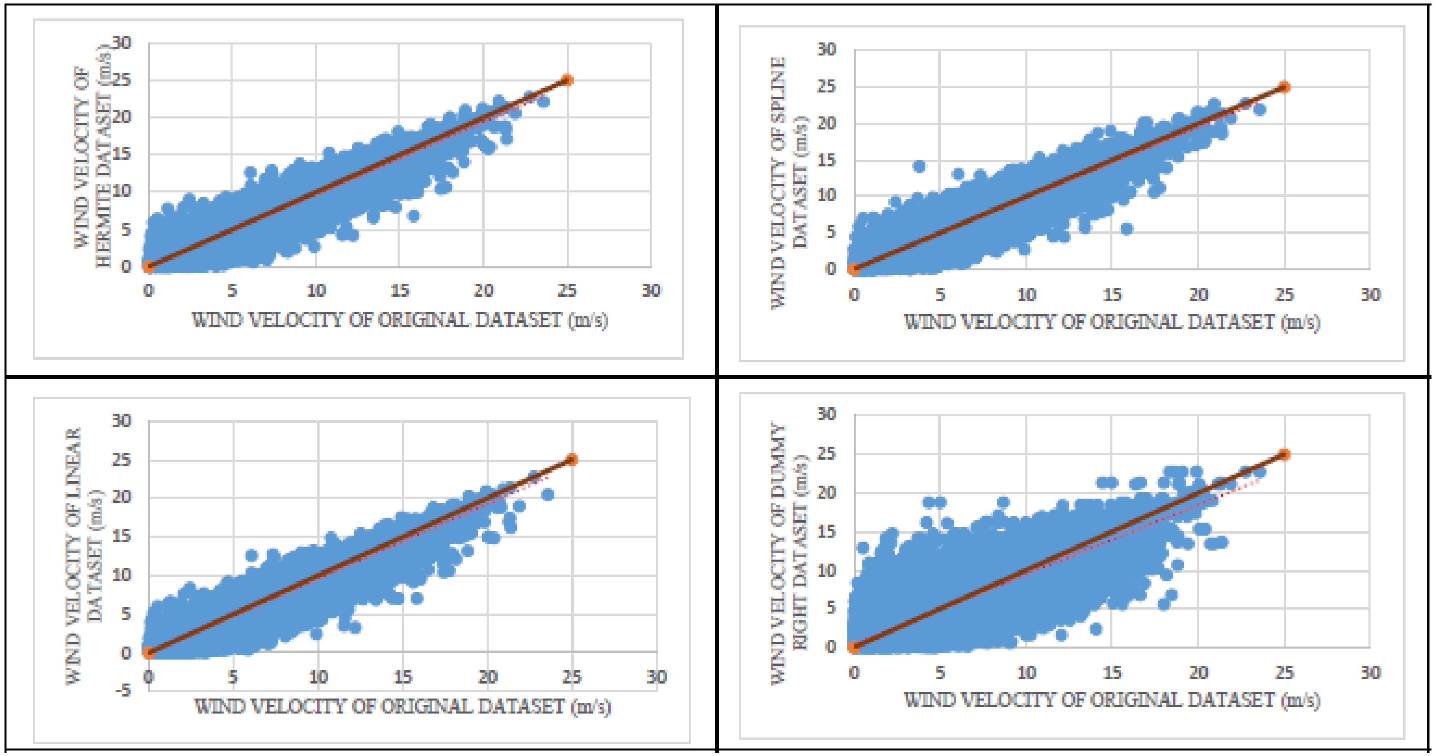
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.25	9.77	4.38	8.18	3.07	6.85	2.51	6.20	-	-	-	-
1-) Hermite	6.55	10.02	4.48	8.29	3.04	6.82	2.42	6.09	4.84	2.39	-1.10	-3.72
2-) Spline	6.44	9.92	4.46	8.25	3.07	6.85	2.47	6.15	3.09	1.72	-0.21	-1.67
3-) Linear	6.45	9.95	4.42	8.23	3.00	6.78	2.39	6.05	3.29	0.90	-2.49	-5.04
9-) Dummy Right	6.64	9.97	4.56	8.26	3.13	6.85	2.52	6.14	6.24	4.17	1.86	0.14



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.36	10.77	8.85	11.07	-	-
1-) Hermite	8.57	11.11	9.13	11.47	2.43	3.13
2-) Spline	8.80	11.12	9.38	11.48	5.20	5.97
3-) Linear	8.60	11.12	9.17	11.48	2.85	3.62
9-) Dummy Right	8.97	10.68	9.54	11.02	7.18	7.77

Figure A.42. Wave Analysis of Point N_4

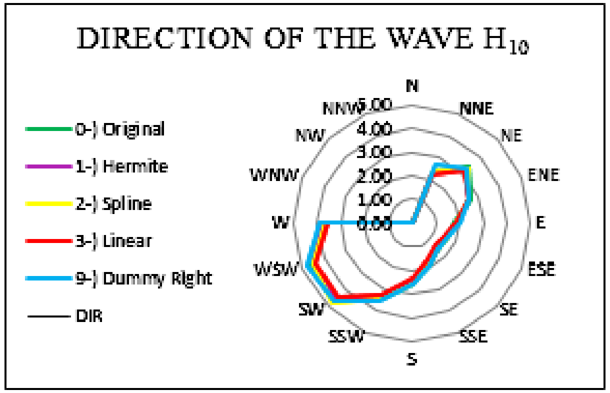
POINT N_5 - N: 44.49° E: 34.69°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.9223	0.0614	0.1465	0.1813	1.0030	0.1604
2	Spline	0.9202	0.0343	0.1461	0.1818	1.0114	0.1600
3	Linear	0.9220	0.0992	0.1521	0.1851	0.9949	0.1666
9	D. Right	0.7391	0.0165	0.2623	0.3582	1.0163	0.2873

Figure A.43. Wind Analysis of Point N_5

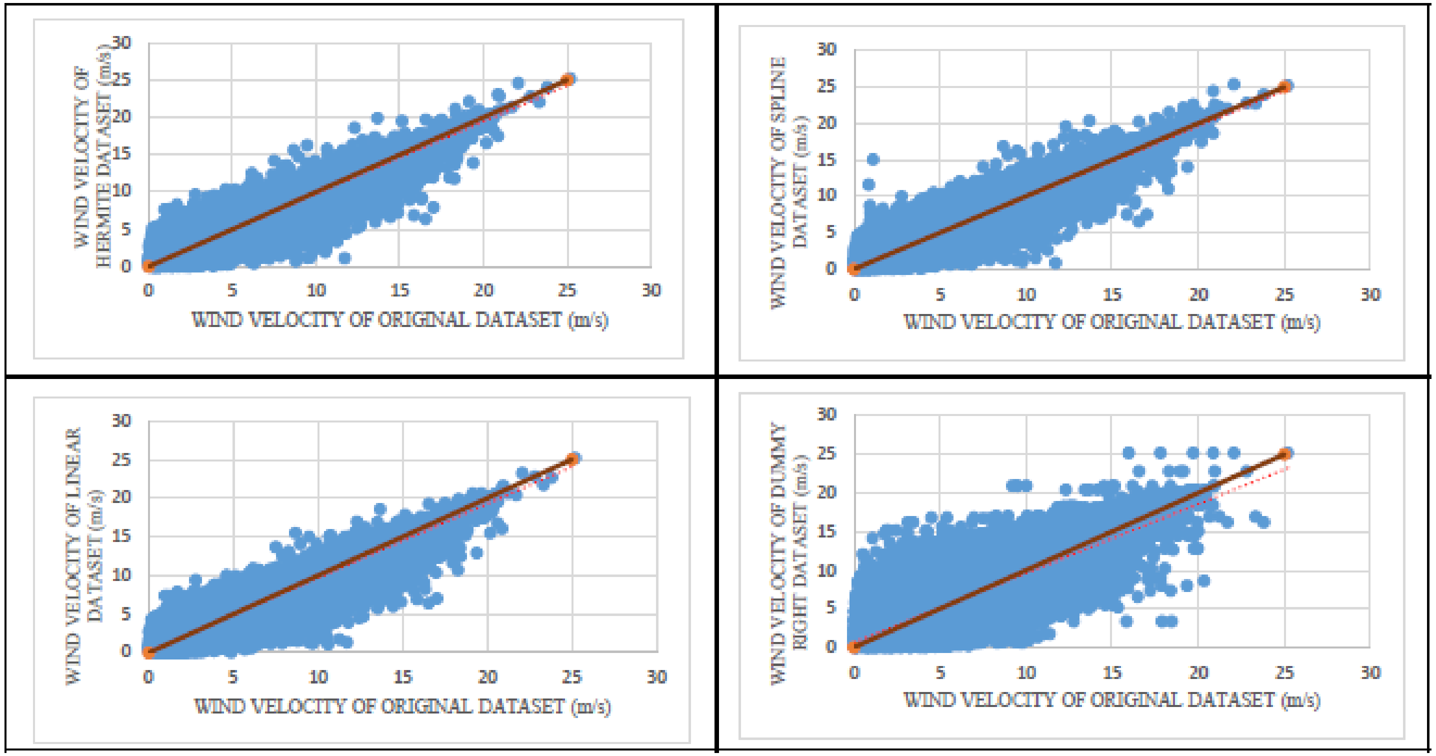
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	6.69	10.02	4.70	8.40	3.31	7.06	2.73	6.40	-	-	-	-
1-) Hermite	6.31	9.74	4.48	8.21	3.20	6.94	2.65	6.32	-5.56	-4.65	-3.35	-2.76
2-) Spline	6.74	10.07	4.73	8.44	3.33	7.08	2.72	6.40	0.74	0.58	0.37	-0.25
3-) Linear	6.19	9.66	4.39	8.13	3.13	6.87	2.59	6.24	-7.36	-6.60	-5.52	-5.15
9-) Dummy Right	6.81	10.01	4.80	8.40	3.39	7.06	2.79	6.40	1.83	2.05	2.36	2.13



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.28	11.08	8.81	11.43	-	-
1-) Hermite	8.16	11.27	8.68	11.63	-1.50	-1.46
2-) Spline	8.51	11.05	9.07	11.41	2.78	2.90
3-) Linear	7.97	11.08	8.49	11.43	-3.70	-3.67
9-) Dummy Right	8.18	11.42	8.69	11.77	-1.16	-1.36

Figure A.44. Wave Analysis of Point N_5

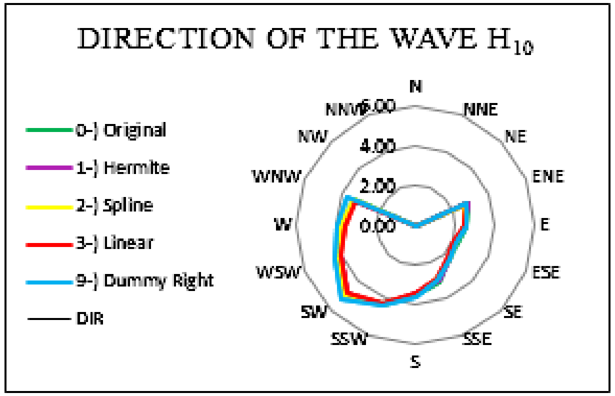
POINT N_6 - N: 44.80° E: 35.94°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.9222	0.0336	0.1296	0.1642	0.9979	0.1420
2	Spline	0.9201	0.0098	0.1304	0.1638	1.0137	0.1429
3	Linear	0.9205	0.0680	0.1338	0.1655	0.9832	0.1465
9	D. Right	0.7252	-0.0070	0.2419	0.3373	1.0186	0.2650

Figure A.45. Wind Analysis of Point N_6

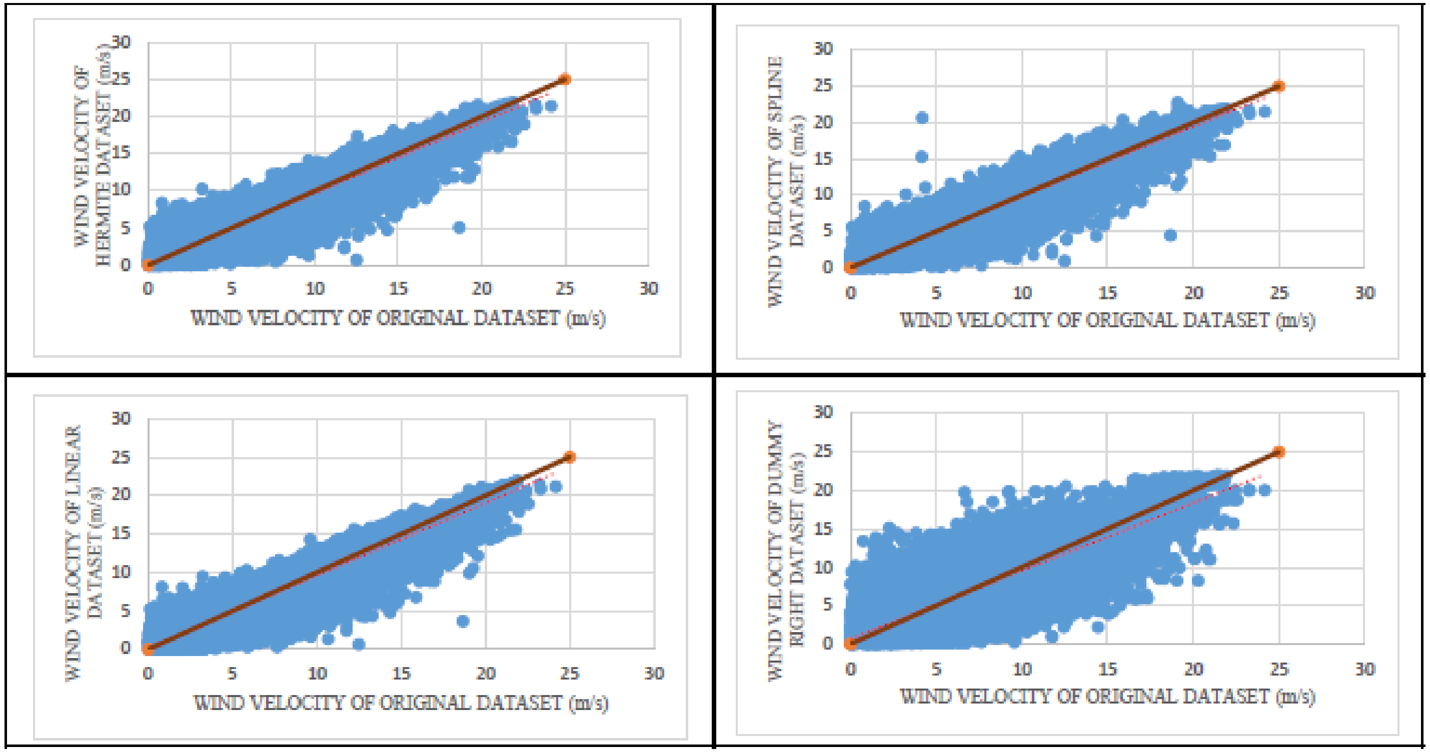
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.05	10.40	5.00	8.76	3.56	7.39	2.94	6.72	-	-	-	-
1-) Hermite	6.95	10.32	4.87	8.64	3.42	7.24	2.79	6.54	-1.50	-2.53	-3.94	-4.98
2-) Spline	7.19	10.50	5.02	8.77	3.50	7.32	2.84	6.60	1.92	0.38	-1.76	-3.33
3-) Linear	6.86	10.26	4.79	8.58	3.35	7.17	2.73	6.47	-2.77	-4.11	-5.95	-7.30
9-) Dummy Right	7.65	10.69	5.29	8.89	3.65	7.38	2.94	6.63	8.40	5.88	2.40	-0.16



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.56	11.28	9.11	11.64	-	-
1-) Hermite	8.69	11.09	9.27	11.46	1.45	1.80
2-) Spline	8.89	11.52	9.49	11.90	3.80	4.16
3-) Linear	8.48	10.74	9.05	11.09	-0.93	-0.68
9-) Dummy Right	8.97	11.87	9.58	12.27	4.72	5.17

Figure A.46. Wave Analysis of Point N_6

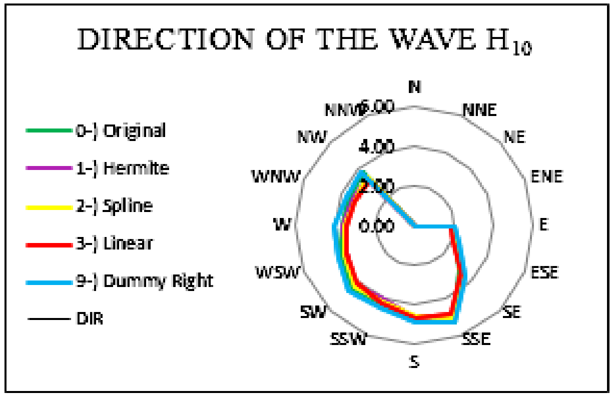
POINT N_7 - N: 44.49° E: 37.50°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.9147	0.0422	0.1389	0.1678	0.9813	0.1522
2	Spline	0.9111	0.0154	0.1405	0.1693	1.0009	0.1539
3	Linear	0.9112	0.0800	0.1452	0.1709	0.9644	0.1591
9	D. Right	0.7172	-0.0062	0.2503	0.3333	1.0014	0.2742

Figure A.47. Wind Analysis of Point N_7

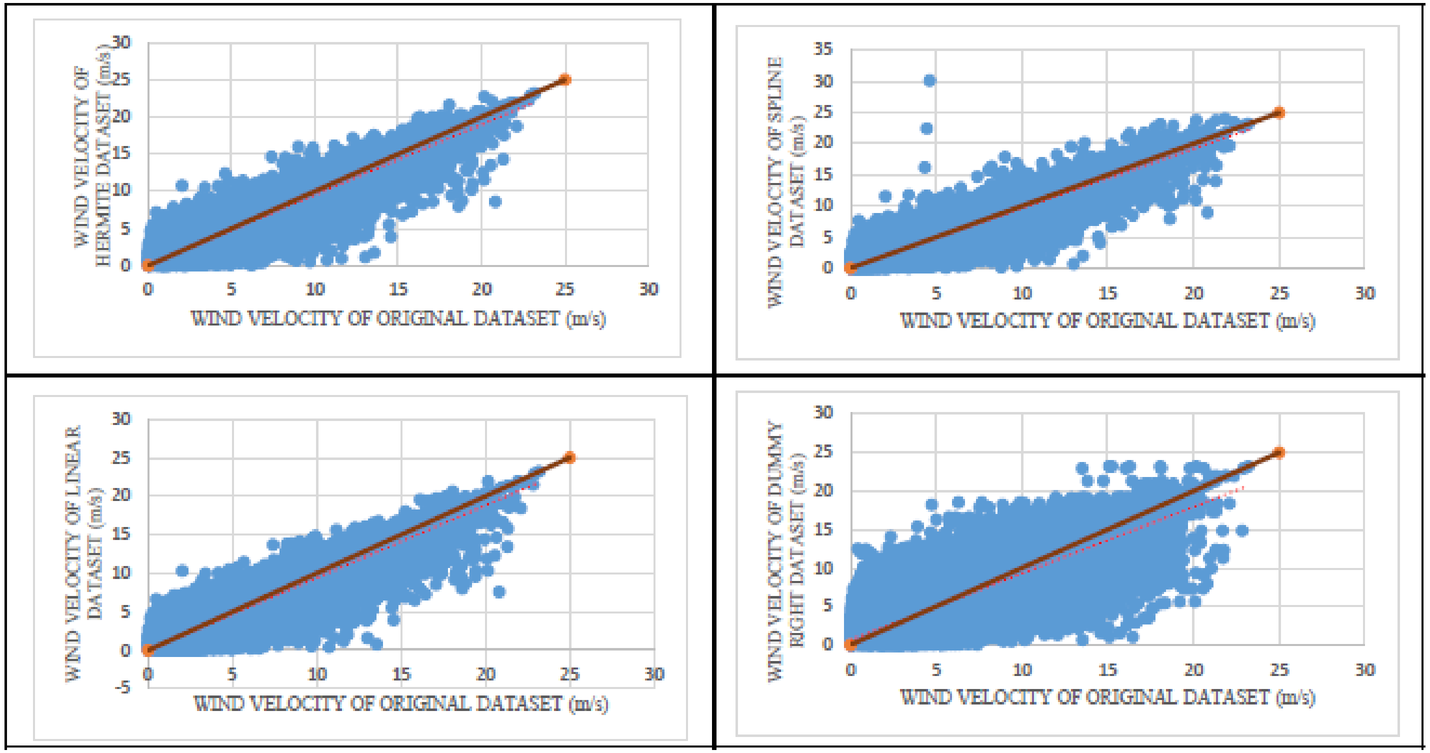
LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.48	10.65	5.27	8.93	3.72	7.50	3.05	6.80	-	-	-	-
1-) Hermite	6.91	10.23	4.97	8.68	3.62	7.41	3.04	6.79	-7.66	-5.55	-2.57	-0.37
2-) Spline	7.12	10.40	5.08	8.78	3.65	7.45	3.04	6.79	-4.90	-3.61	-1.79	-0.44
3-) Linear	6.69	10.08	4.82	8.57	3.55	7.35	3.00	6.75	-10.64	-8.40	-4.55	-1.68
9-) Dummy Right	7.36	10.45	5.25	8.83	3.77	7.48	3.14	6.82	-1.61	-0.32	1.49	2.84



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.76	11.04	9.22	11.33	-	-
1-) Hermite	8.44	10.85	8.86	11.11	-3.66	-3.93
2-) Spline	8.55	11.03	8.97	11.30	-2.37	-2.71
3-) Linear	8.38	11.08	8.80	11.35	-4.35	-4.57
9-) Dummy Right	8.66	11.82	9.10	12.12	-1.09	-1.34

Figure A.48. Wave Analysis of Point N_7

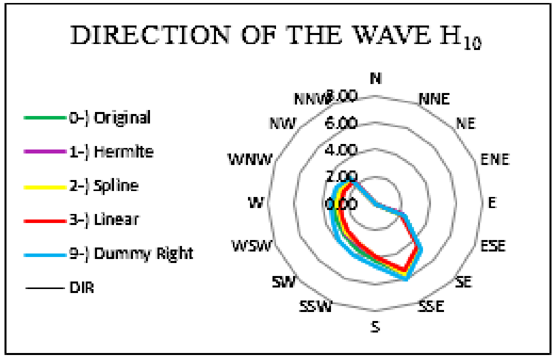
POINT N_8 - N: 43.87° E: 39.06°



Ranking Acc. to Wind Analysis	Interpolation Method	Predic. Skill	Normalized Bias	CVRMSE	Mean Absolute Error	Variance Ratio	Scatter Index
1	Hermite	0.9037	0.0777	0.1788	0.2256	0.9758	0.1959
2	Spline	0.9003	0.0431	0.1782	0.2261	0.9871	0.1952
3	Linear	0.9028	0.1252	0.1878	0.2317	0.9665	0.2057
9	D. Right	0.6813	0.0197	0.3158	0.4425	0.9931	0.3459

Figure A.49. Wind Analysis of Point N_8

LONG TERM WAVE ANALYSIS	H_1	T_1	H_{10}	T_{10}	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_1)%	R.ERROR (H_{10})%	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	7.43	10.47	5.65	9.13	4.41	8.07	3.88	7.56	-	-	-	-
1-) Hermite	7.40	10.47	5.59	9.10	4.33	8.01	3.79	7.49	0.43	1.08	1.84	2.32
2-) Spline	7.50	10.53	5.67	9.16	4.39	8.06	3.84	7.53	-0.97	-0.30	0.50	1.00
3-) Linear	7.13	10.29	5.43	8.98	4.24	7.93	3.73	7.43	3.97	3.96	3.93	3.92
9-) Dummy Right	8.15	10.92	6.06	9.42	4.60	8.20	3.97	7.62	-9.73	-7.23	-4.28	-2.42



EXTREME WAVE ANALYSIS	H_{50}	T_{50}	H_{100}	T_{100}	R.ERROR (H_{50})%	R.ERROR (H_{100})%
ORIGINAL	8.60	10.58	8.92	10.77	-	-
1-) Hermite	8.49	10.49	8.84	10.70	1.29	0.85
2-) Spline	8.73	10.67	9.10	10.89	-1.59	-2.09
3-) Linear	8.45	10.41	8.81	10.63	1.76	1.18
9-) Dummy Right	9.06	12.79	9.50	13.09	-5.41	-6.55

Figure A.50. Wave Analysis of Point N_8

B. WAVE ANALYSIS USING WAVEWATCH III

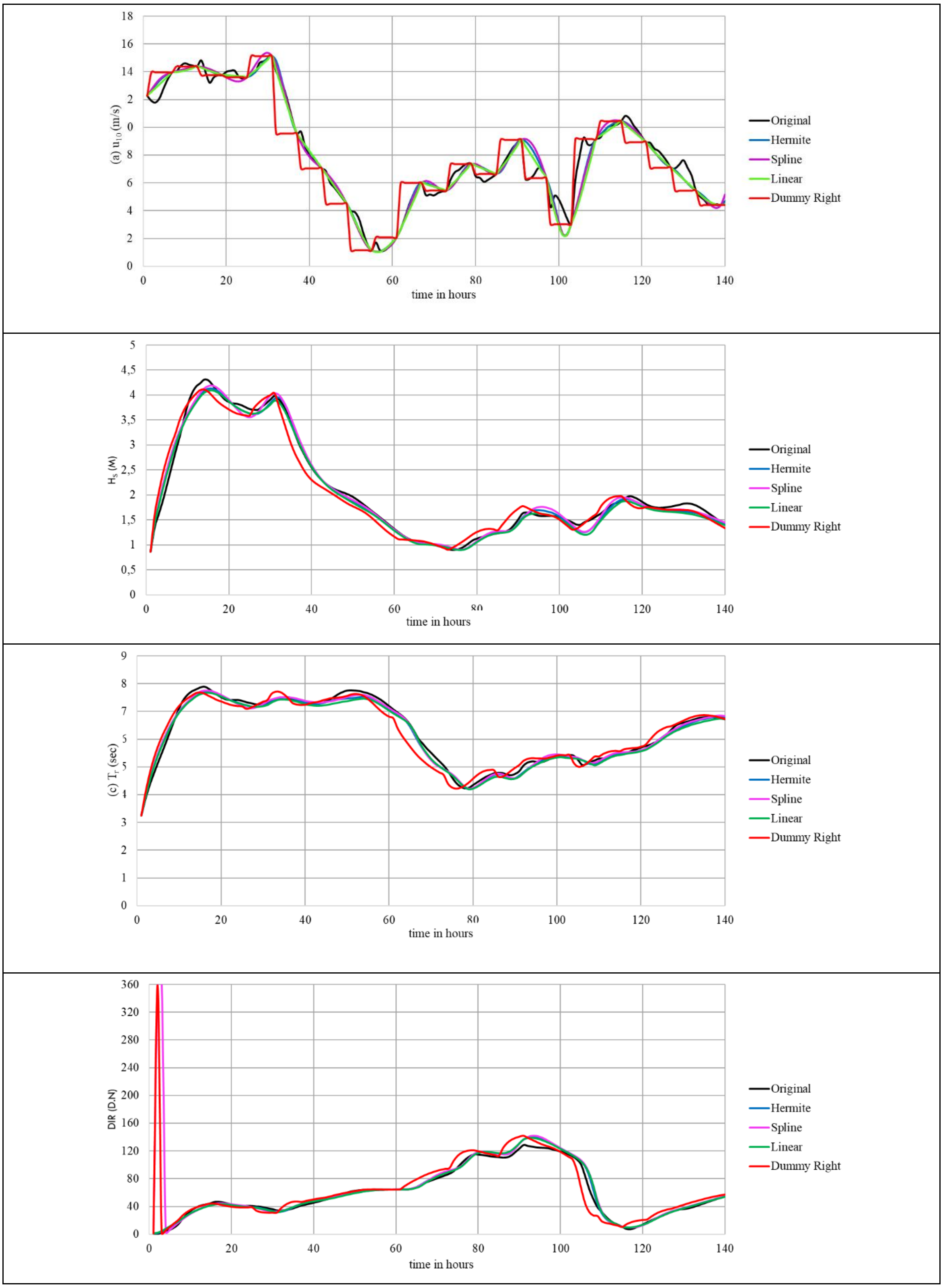


Figure A.51. Wave Analysis of Point SW_1

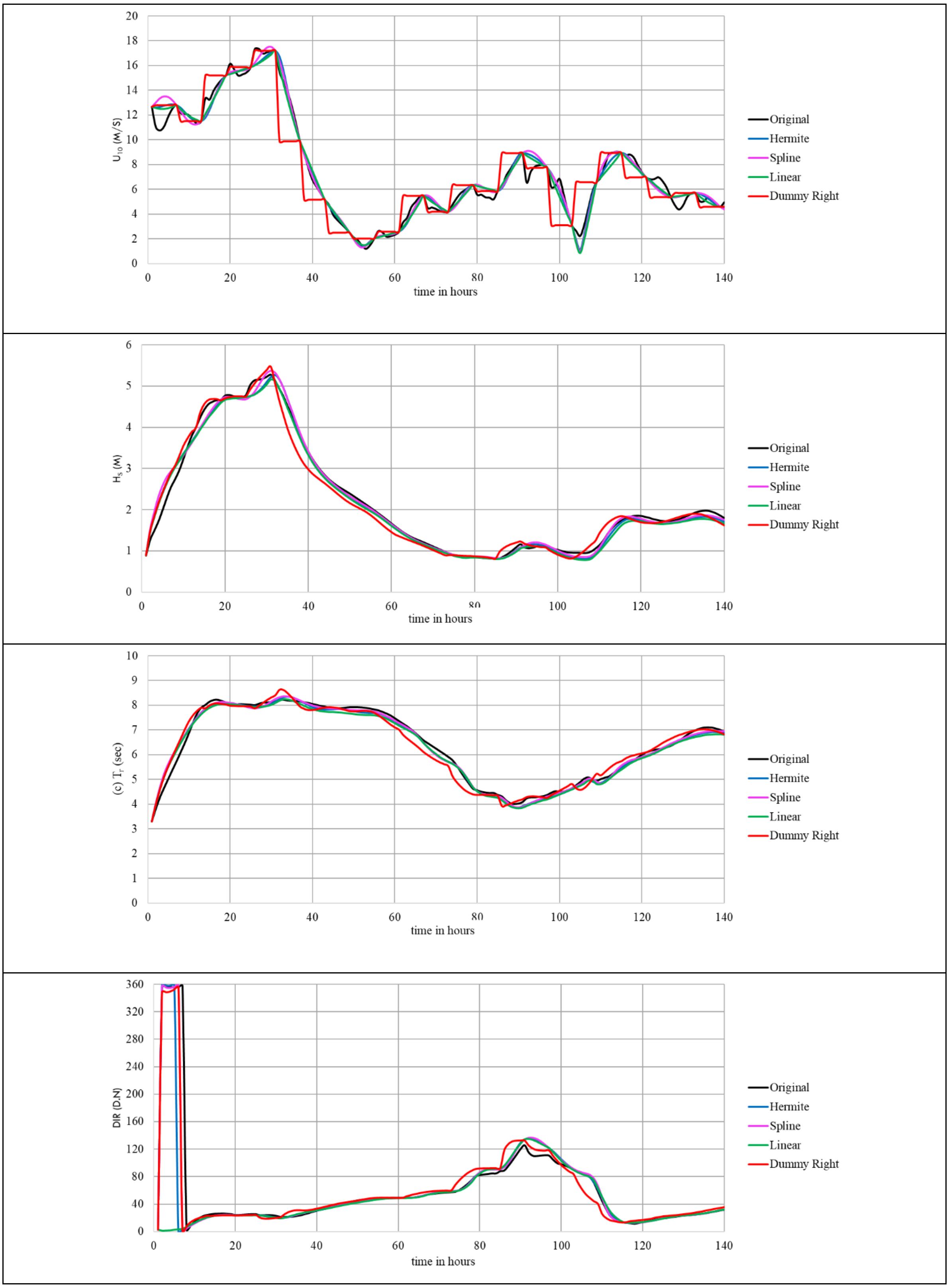


Figure A.52. Wave Analysis of Point SW_2

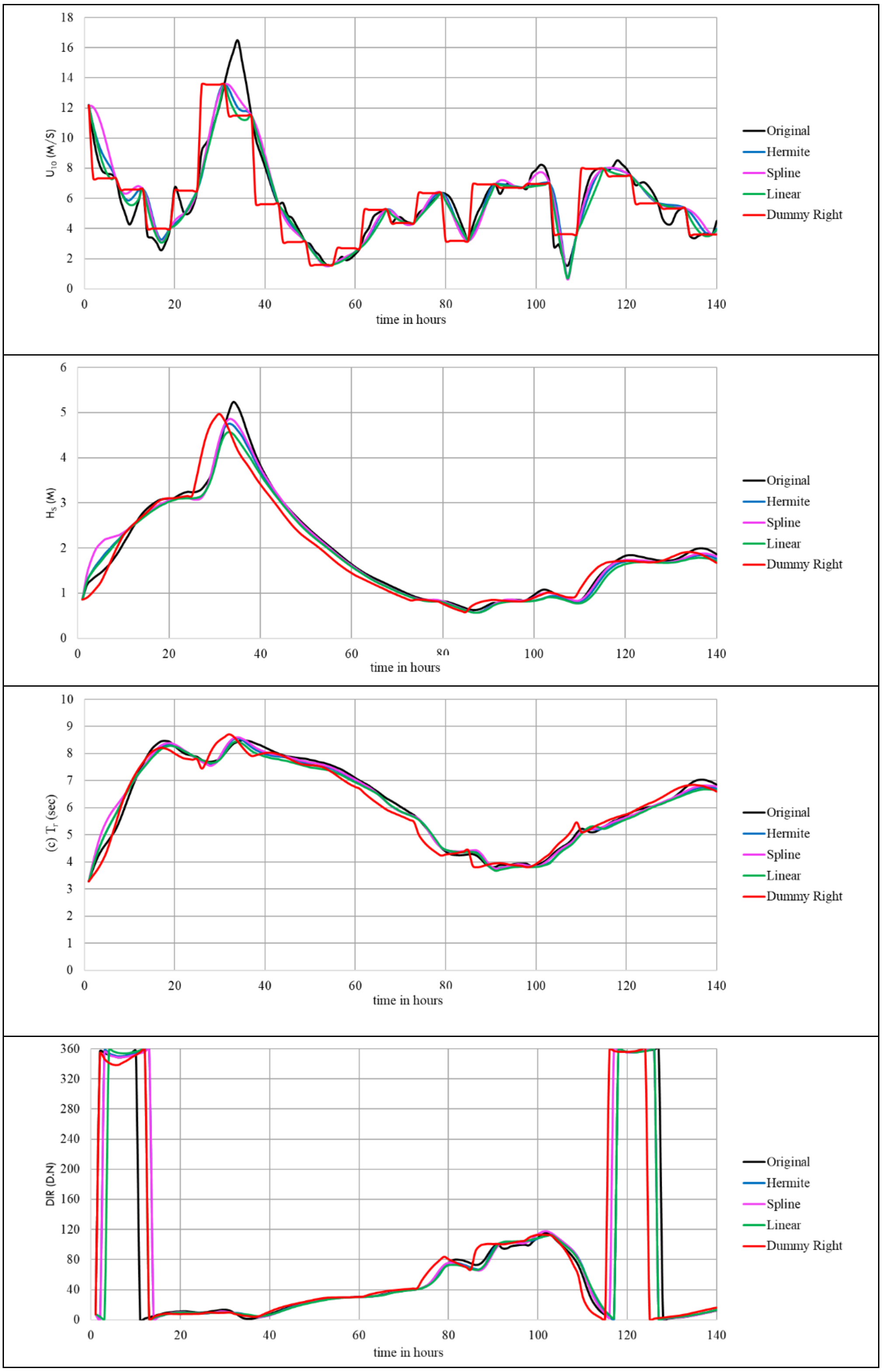


Figure A.53. Wave Analysis of Point SW_3

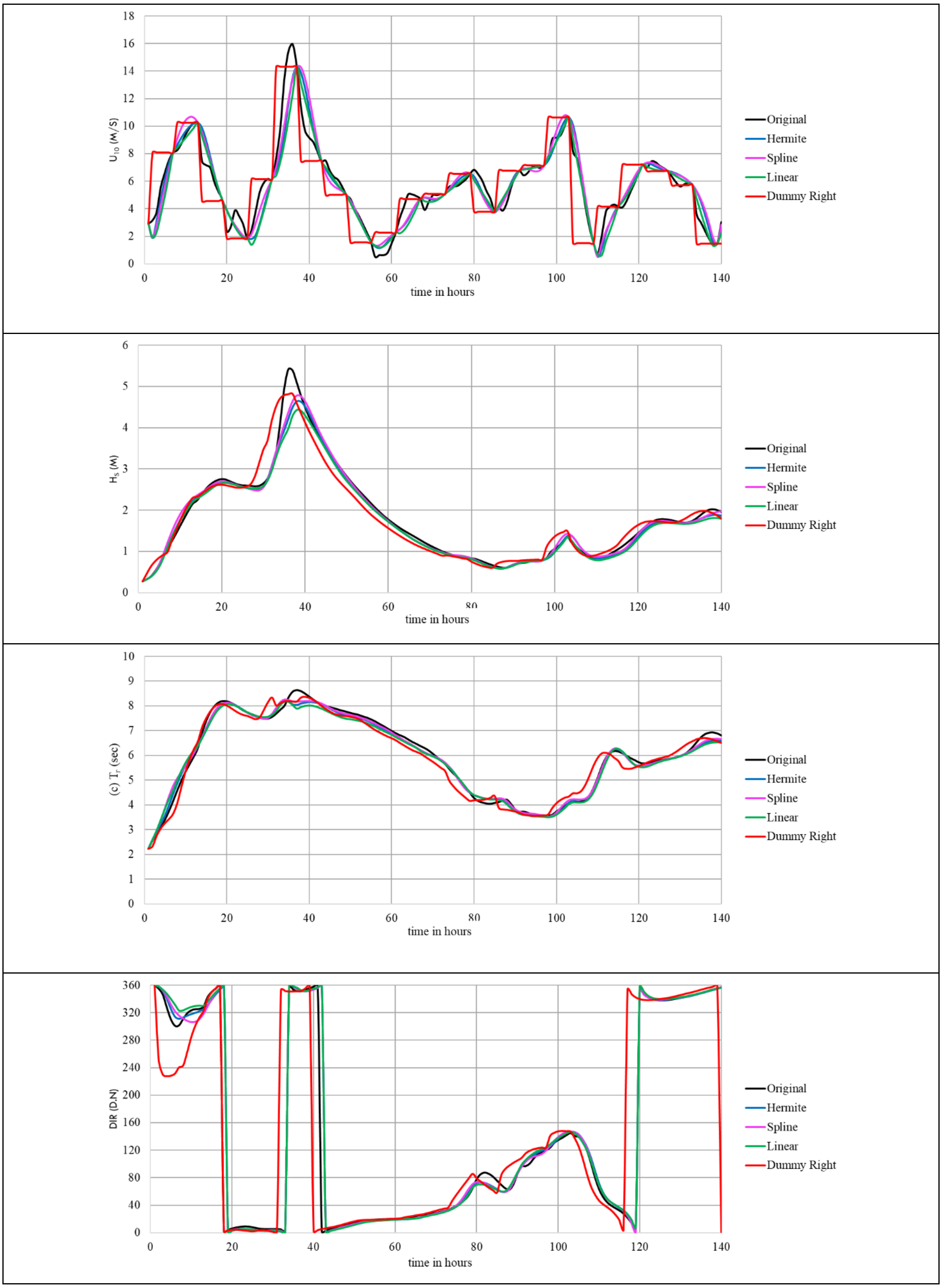


Figure A.54. Wave Analysis of Point SW_4

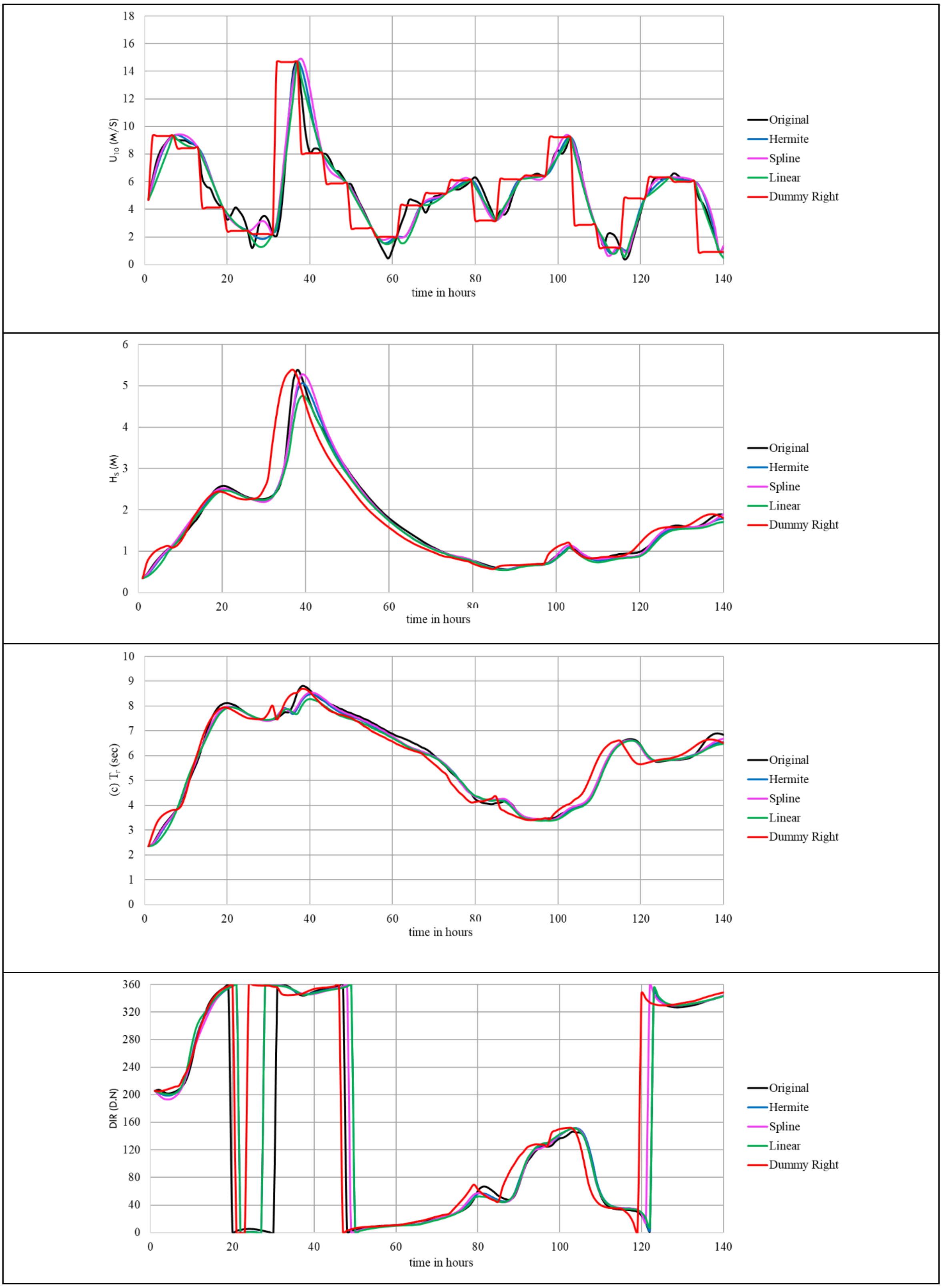


Figure A.55. Wave Analysis of Point SW_5

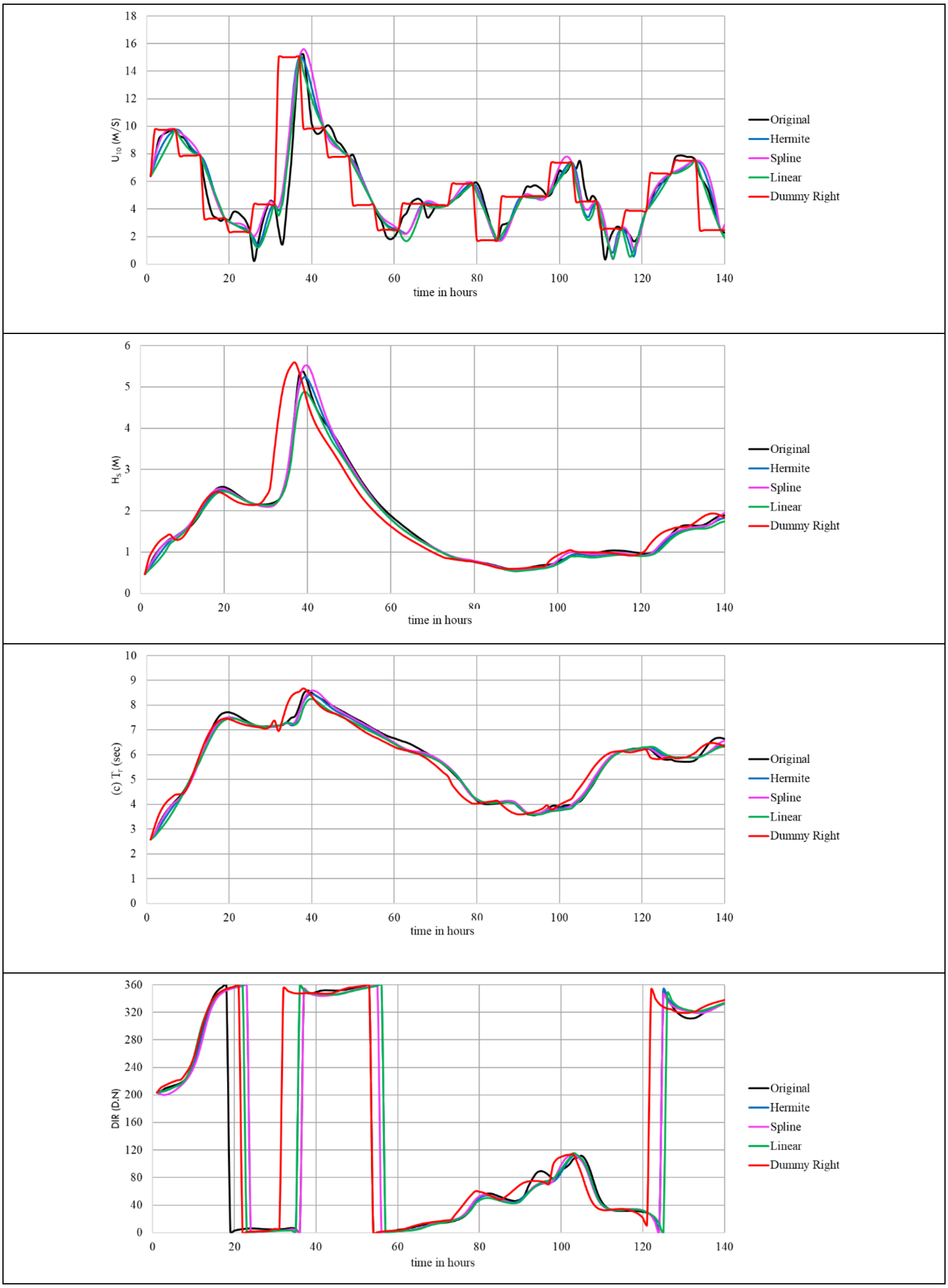


Figure A.56. Wave Analysis of Point SW_6

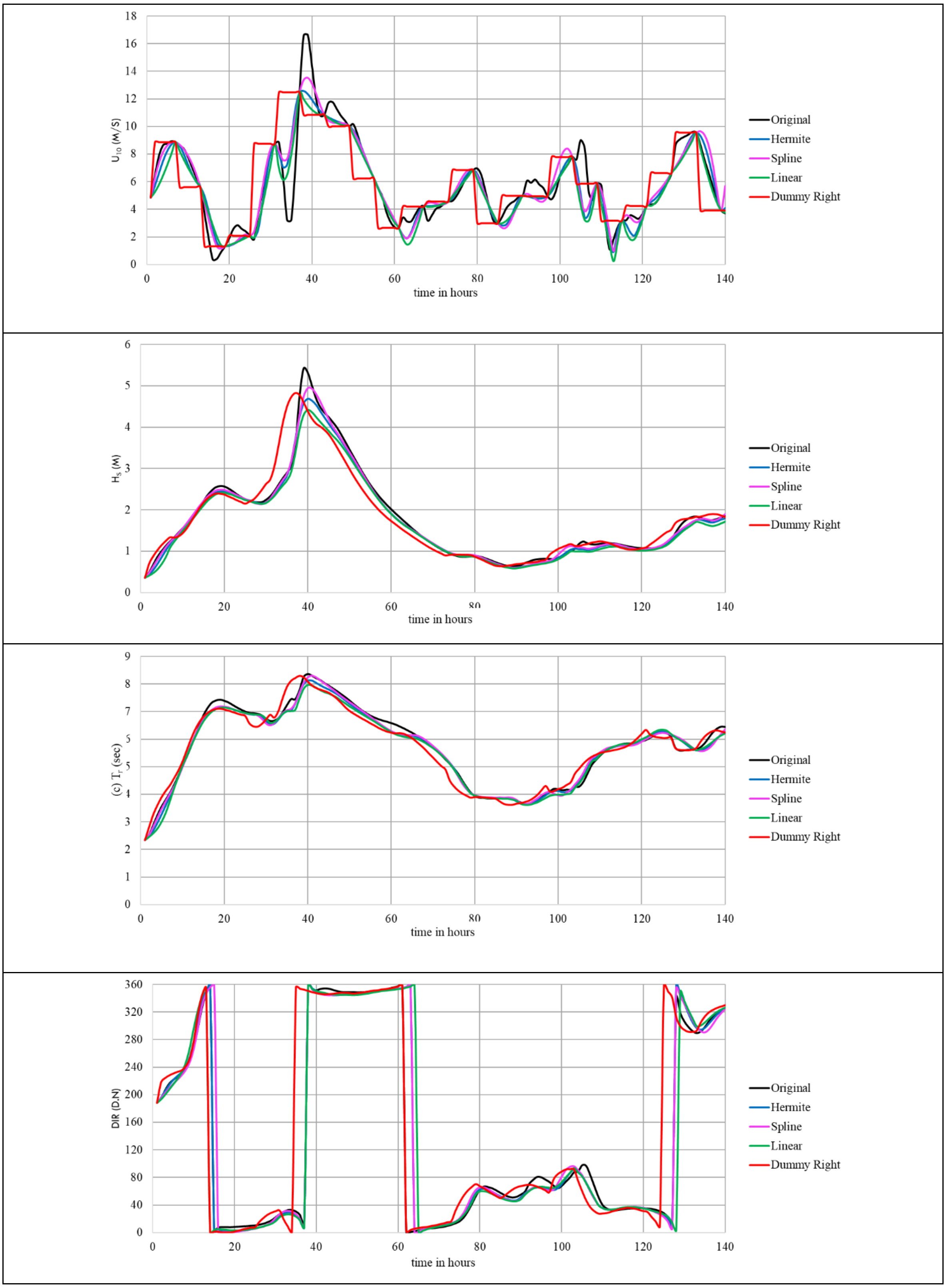


Figure A.57. Wave Analysis of Point SW_7

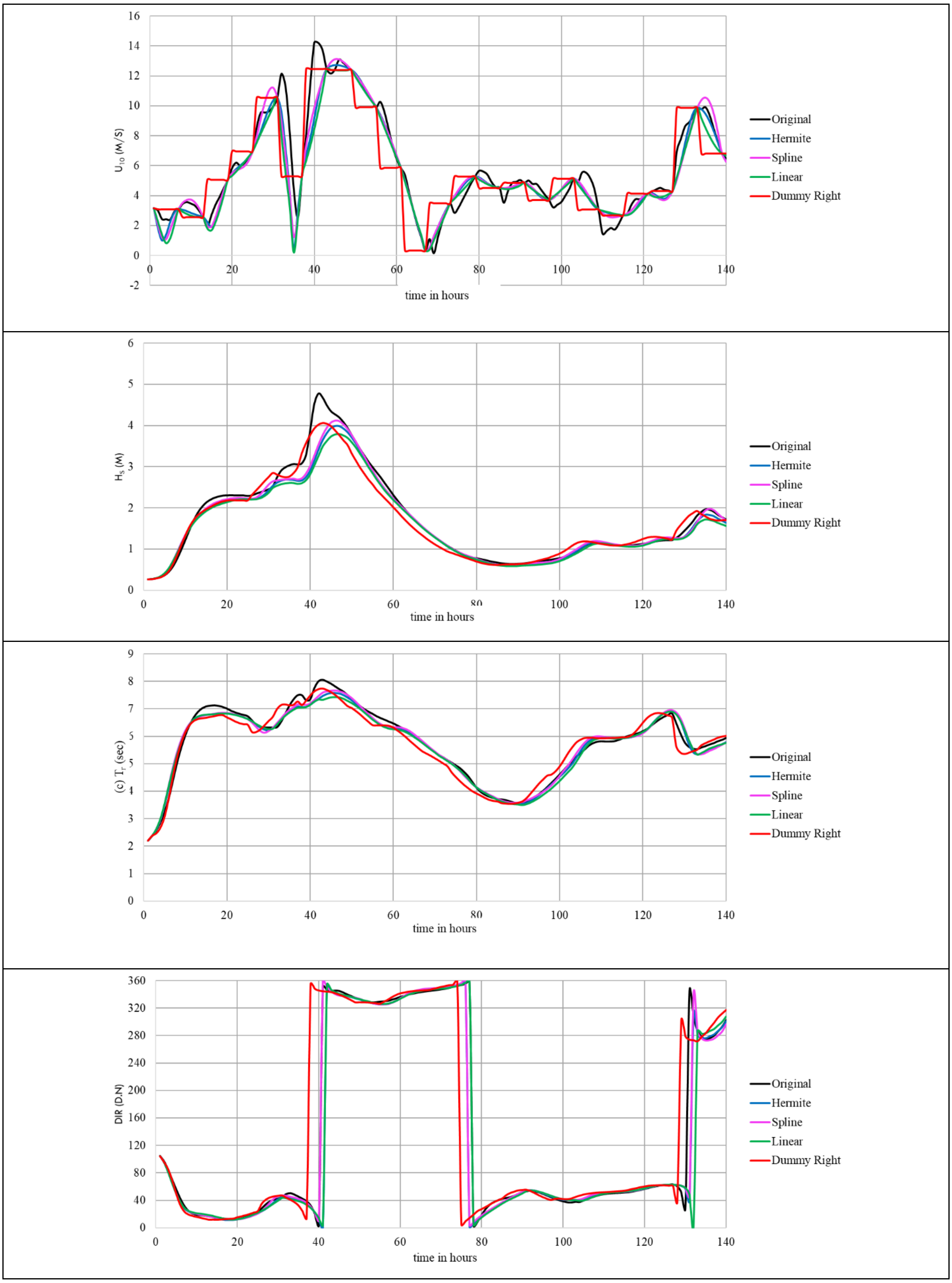


Figure A.58. Wave Analysis of Point SW_8

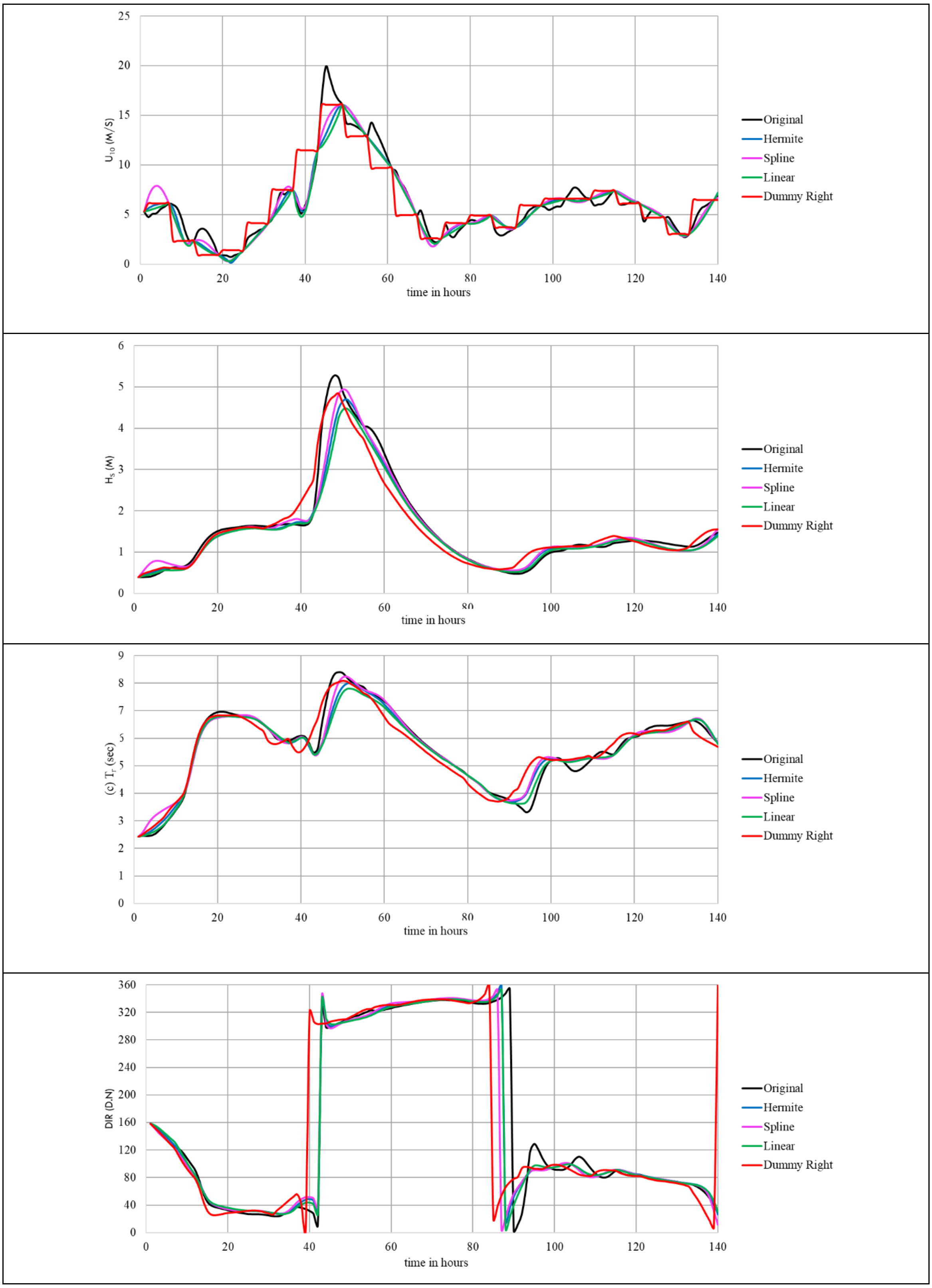


Figure A.59. Wave Analysis of Point SE_1

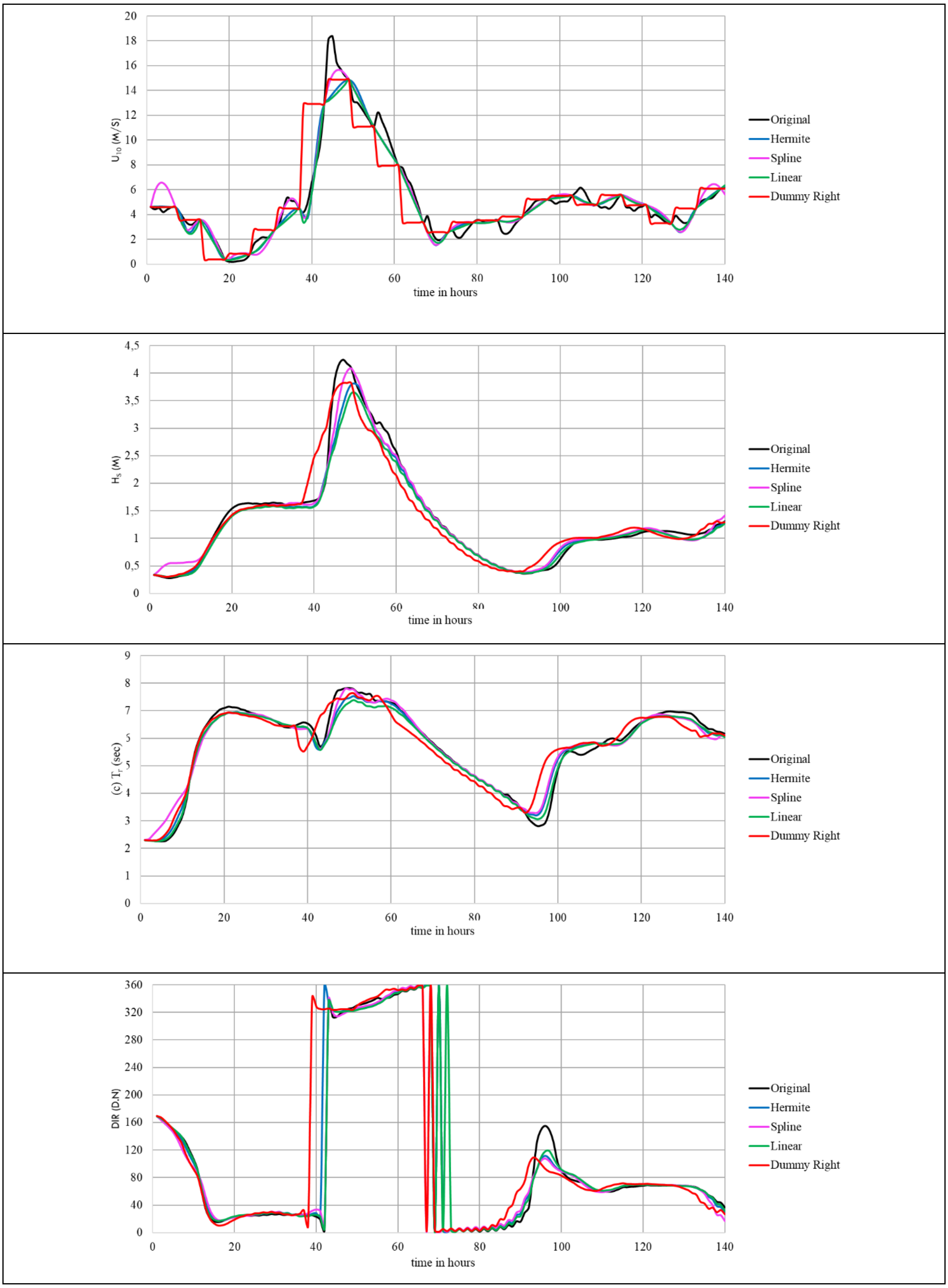


Figure A.60. Wave Analysis of Point SE_2

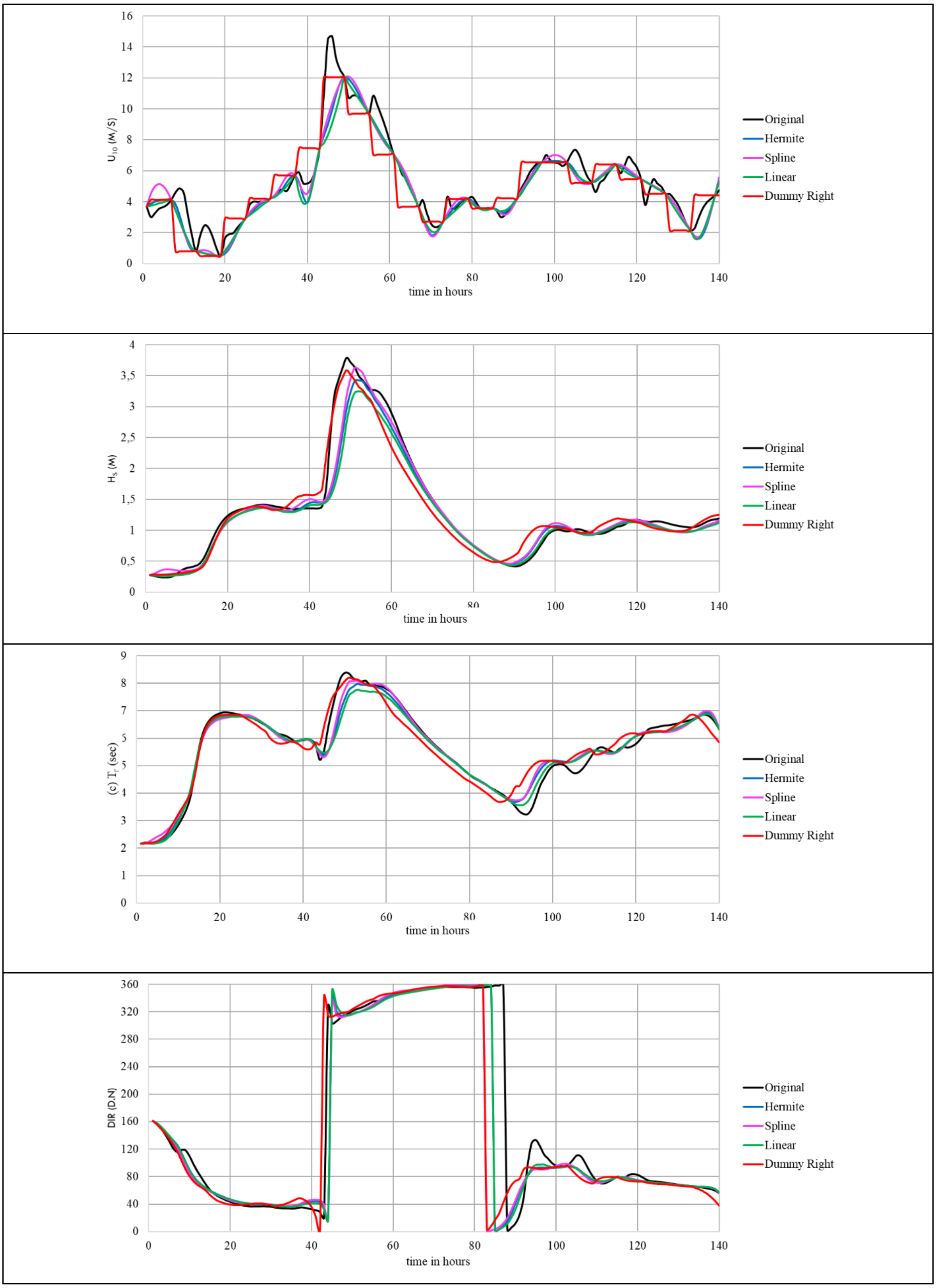


Figure A.61. Wave Analysis of Point SE_3

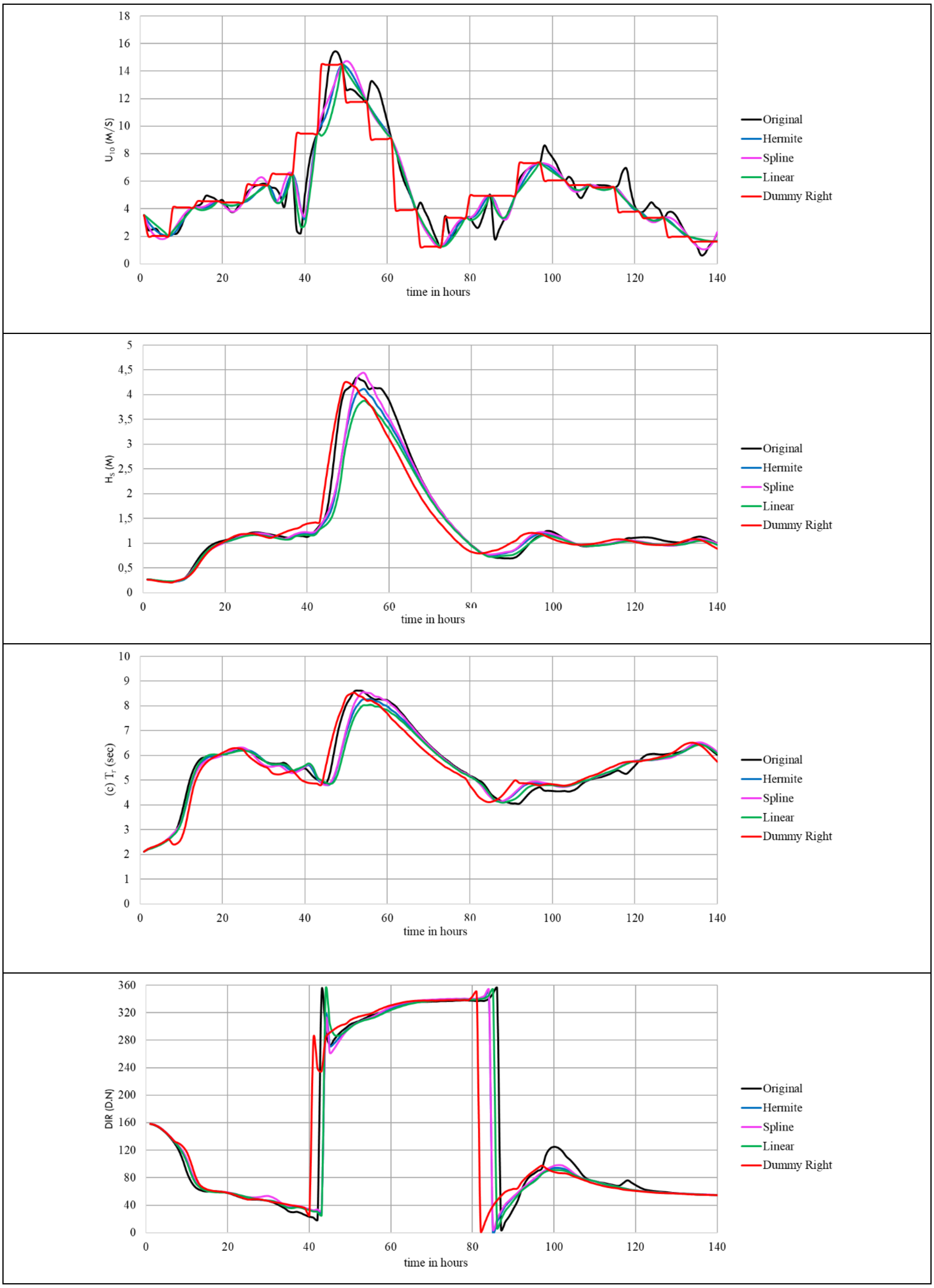


Figure A.62. Wave Analysis of Point SE_4

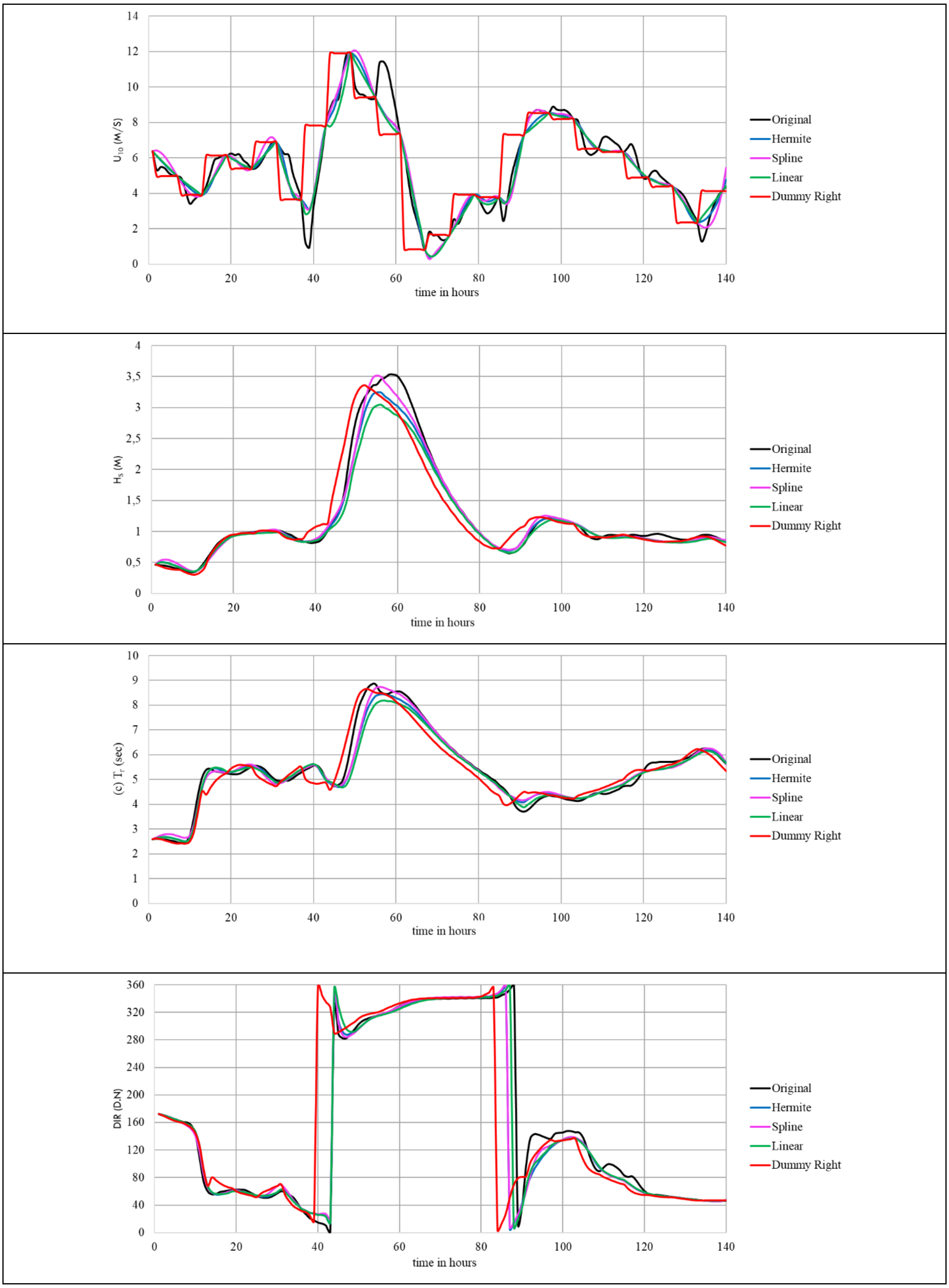


Figure A.63. Wave Analysis of Point SE_5

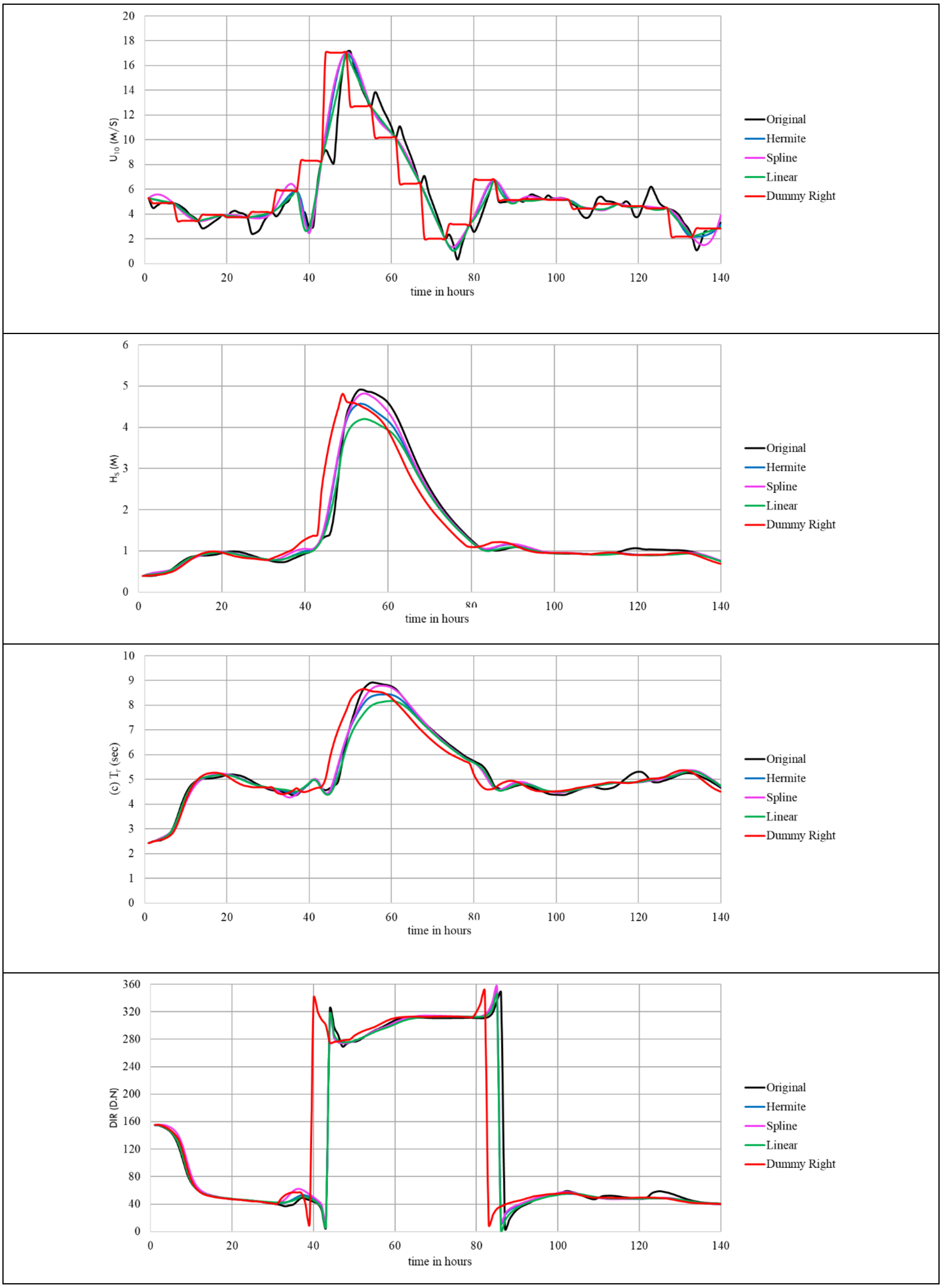


Figure A.64. Wave Analysis of Point SE_6

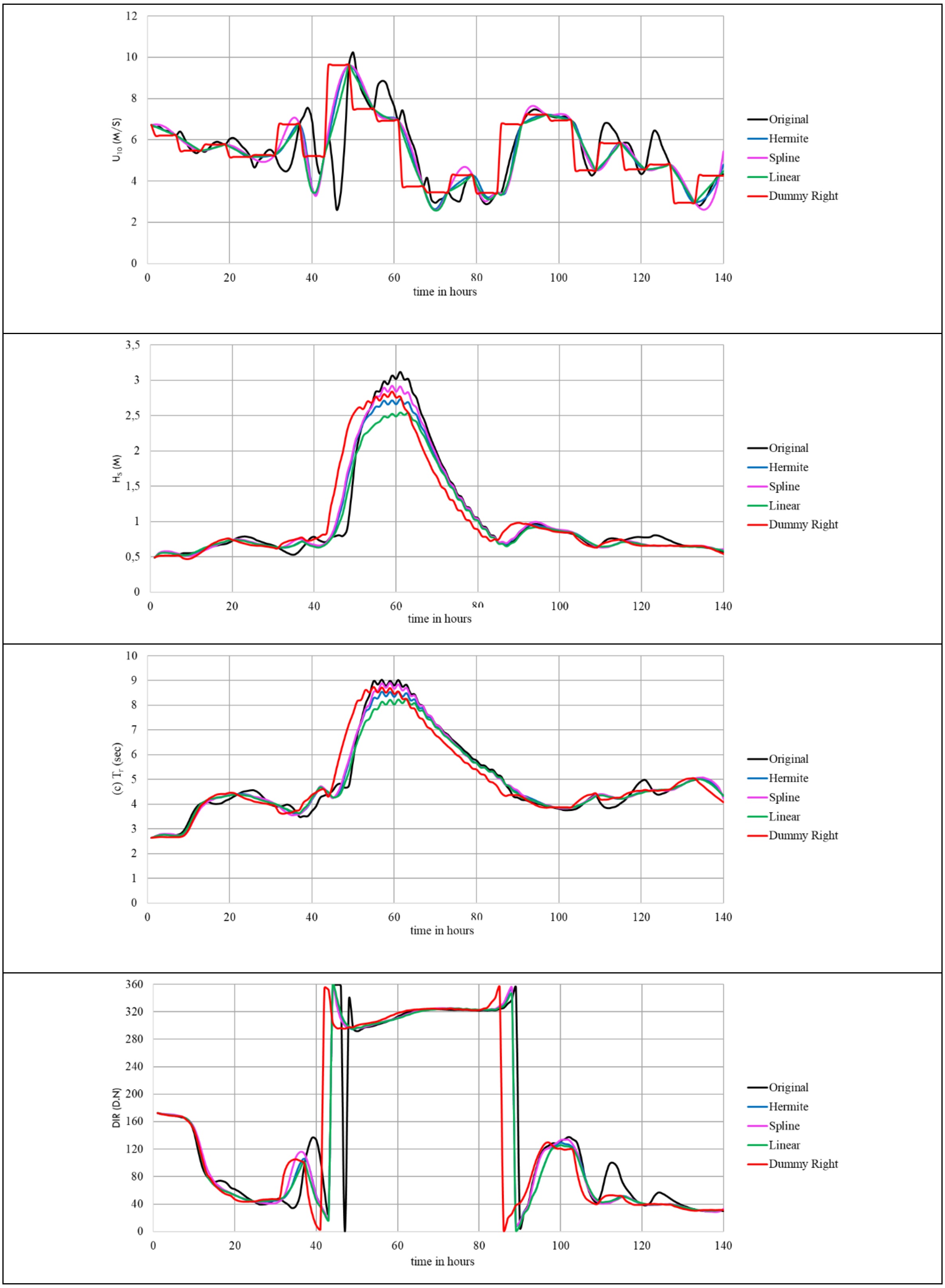


Figure A.65. Wave Analysis of Point SE_7

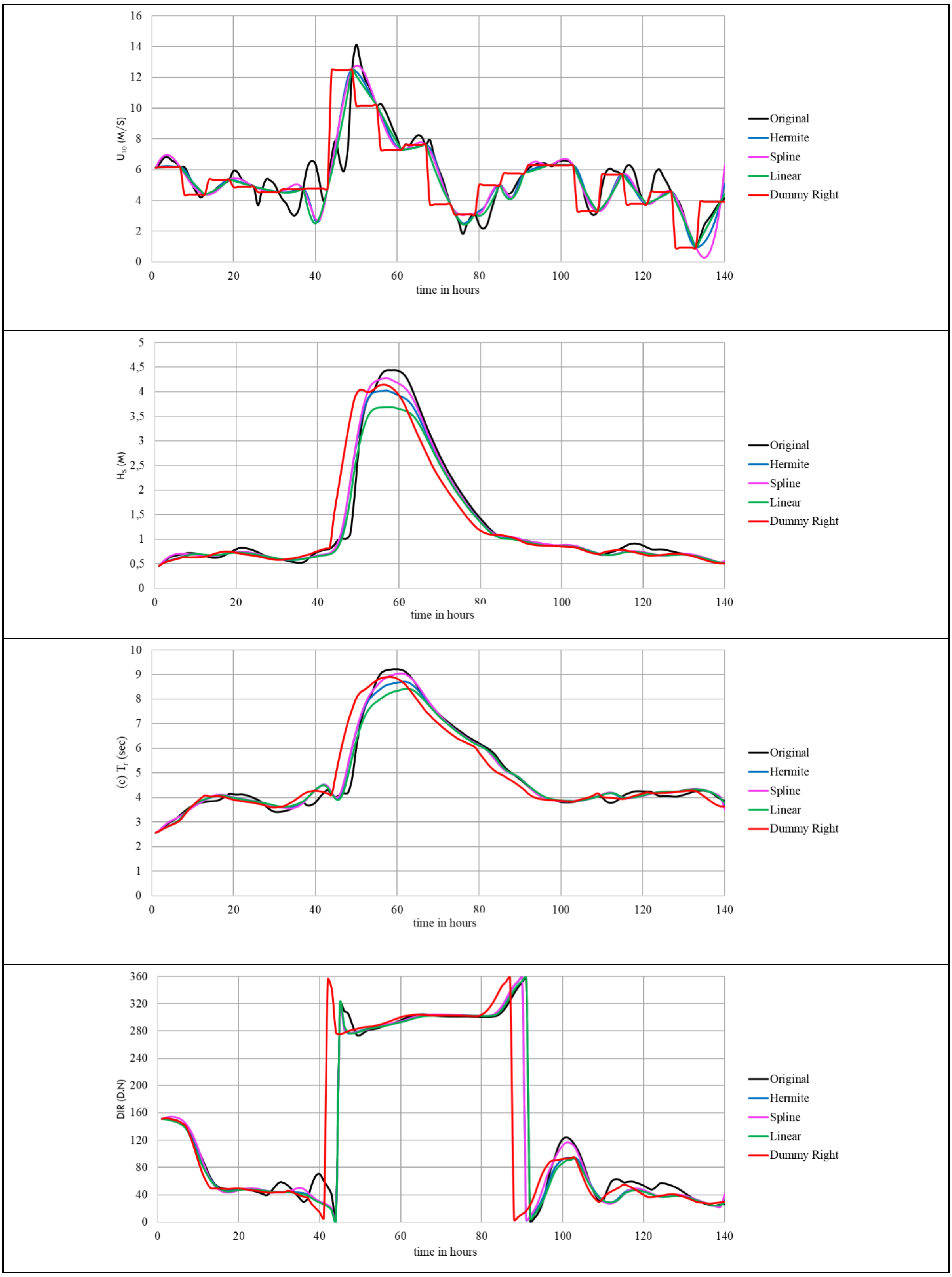


Figure A.66. Wave Analysis of Point SE_8

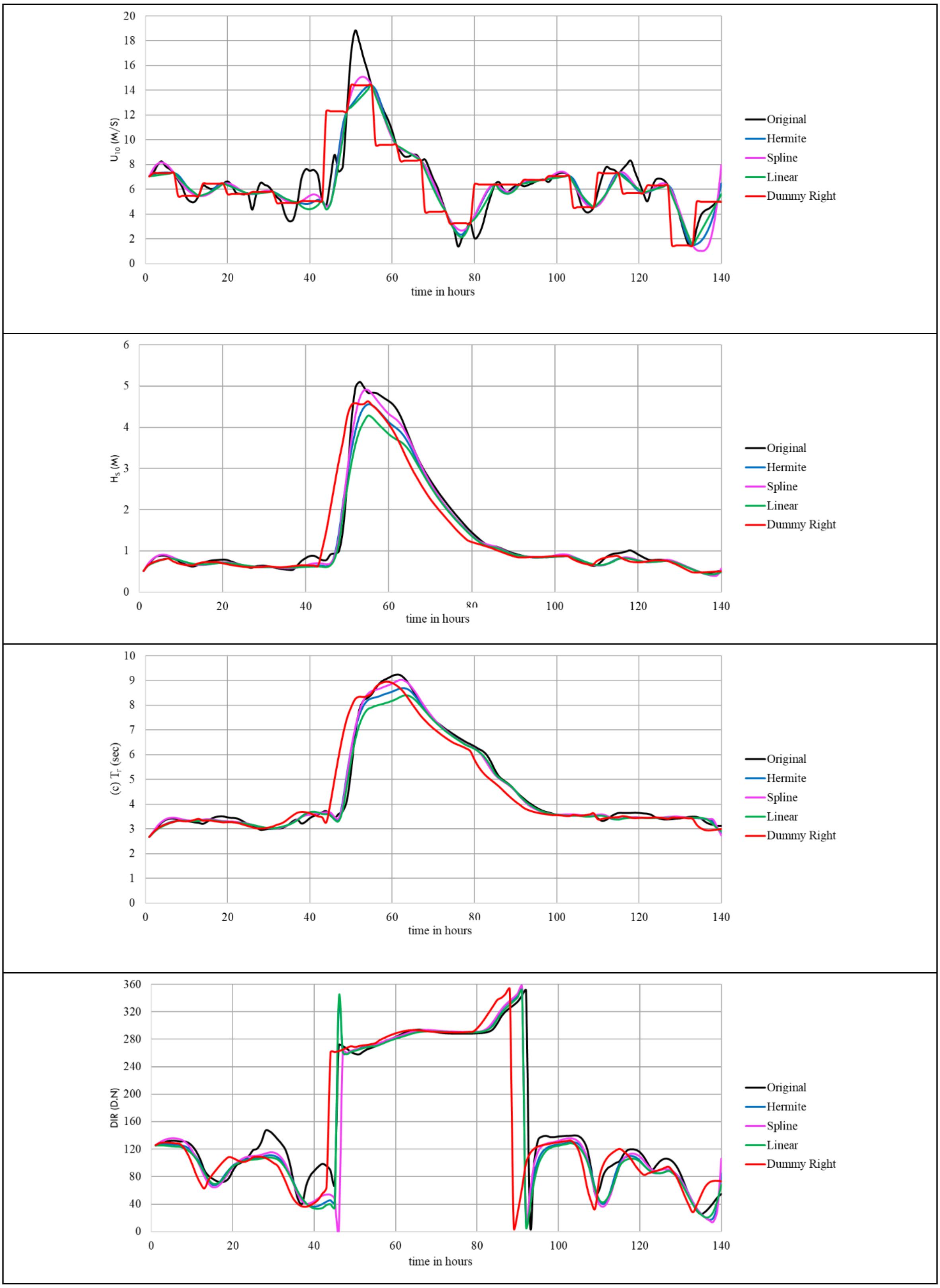


Figure A.67. Wave Analysis of Point SE_9

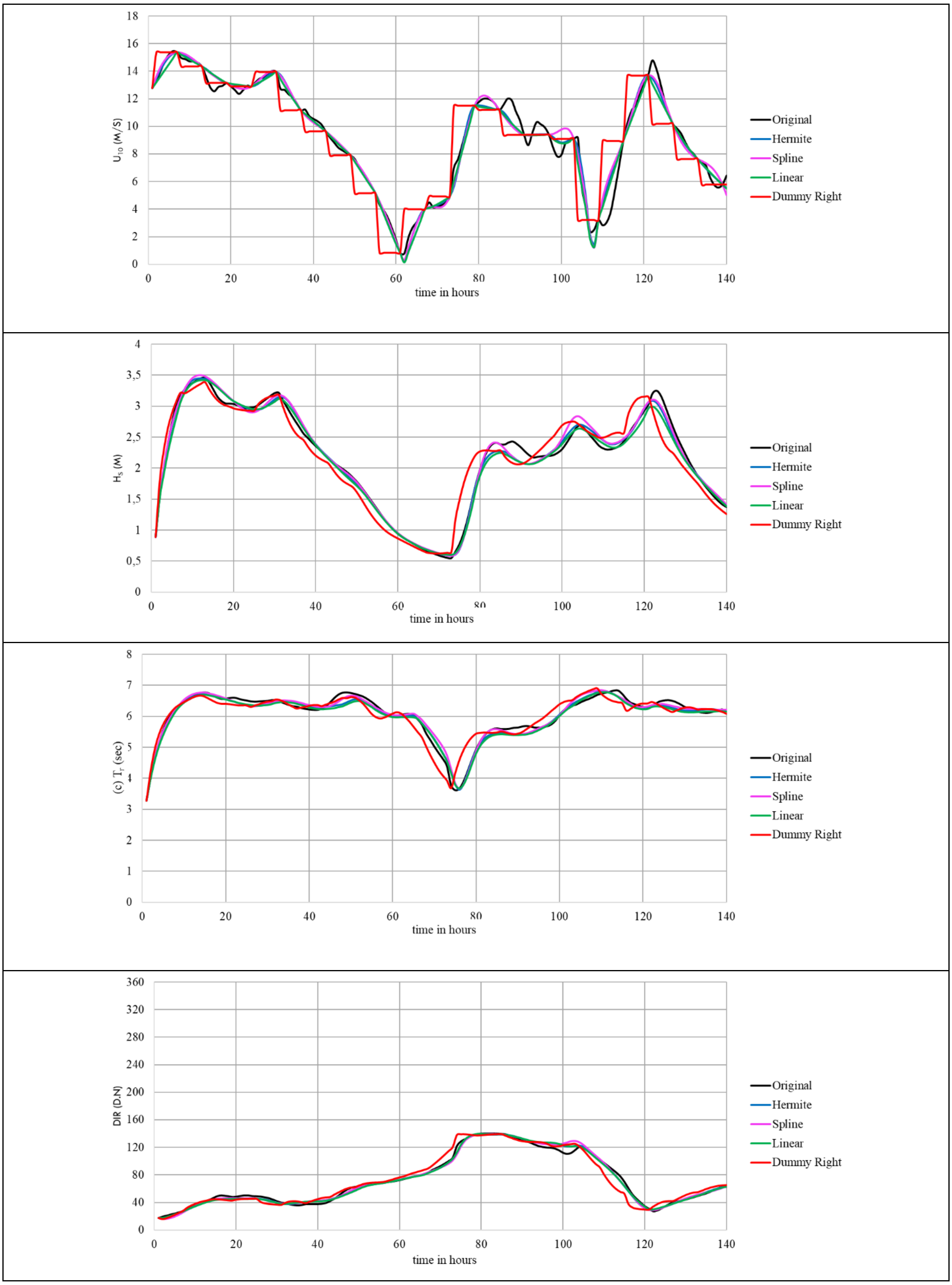


Figure A.68. Wave Analysis of Point N_1

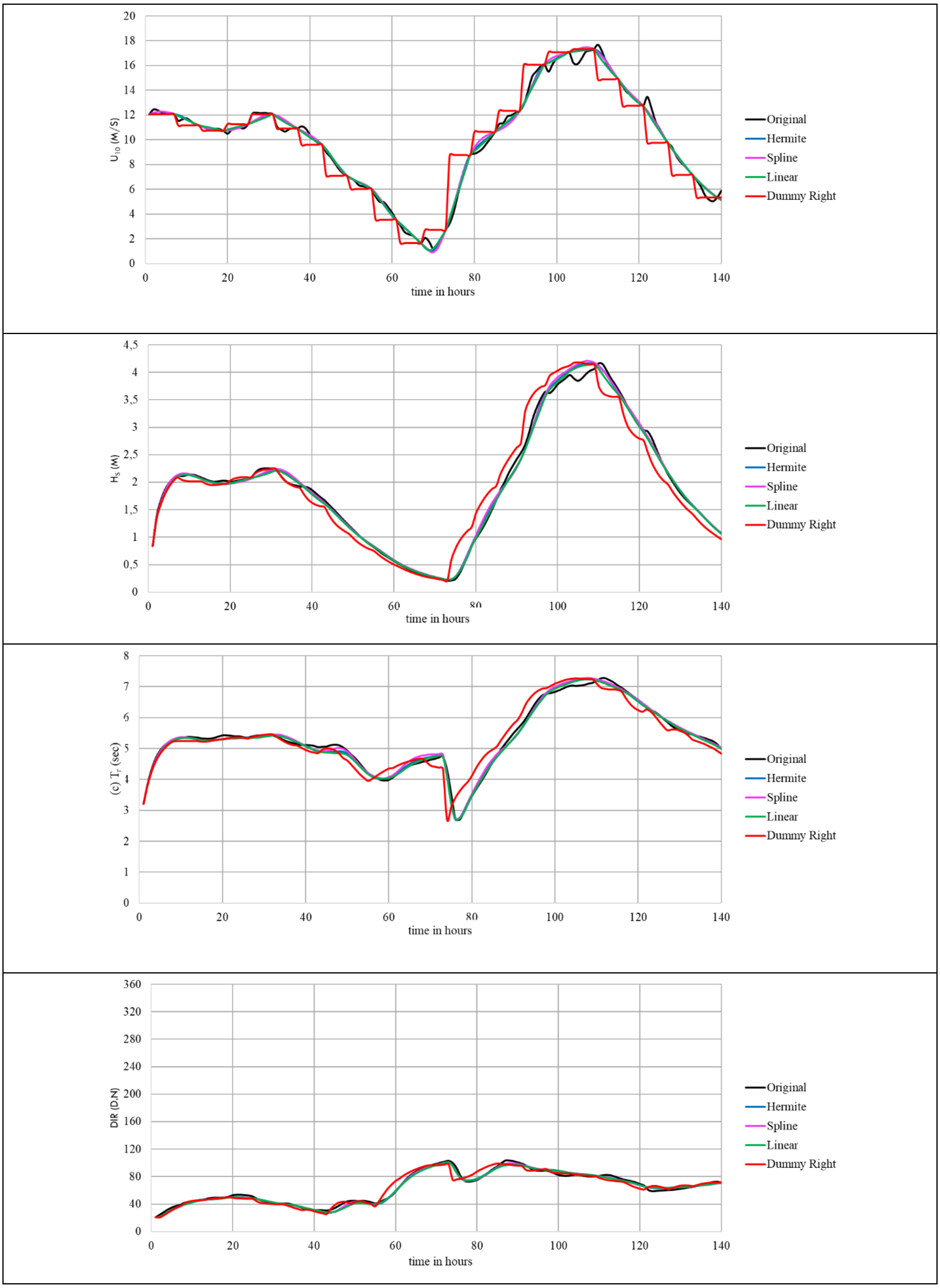


Figure A.69. Wave Analysis of Point N_2

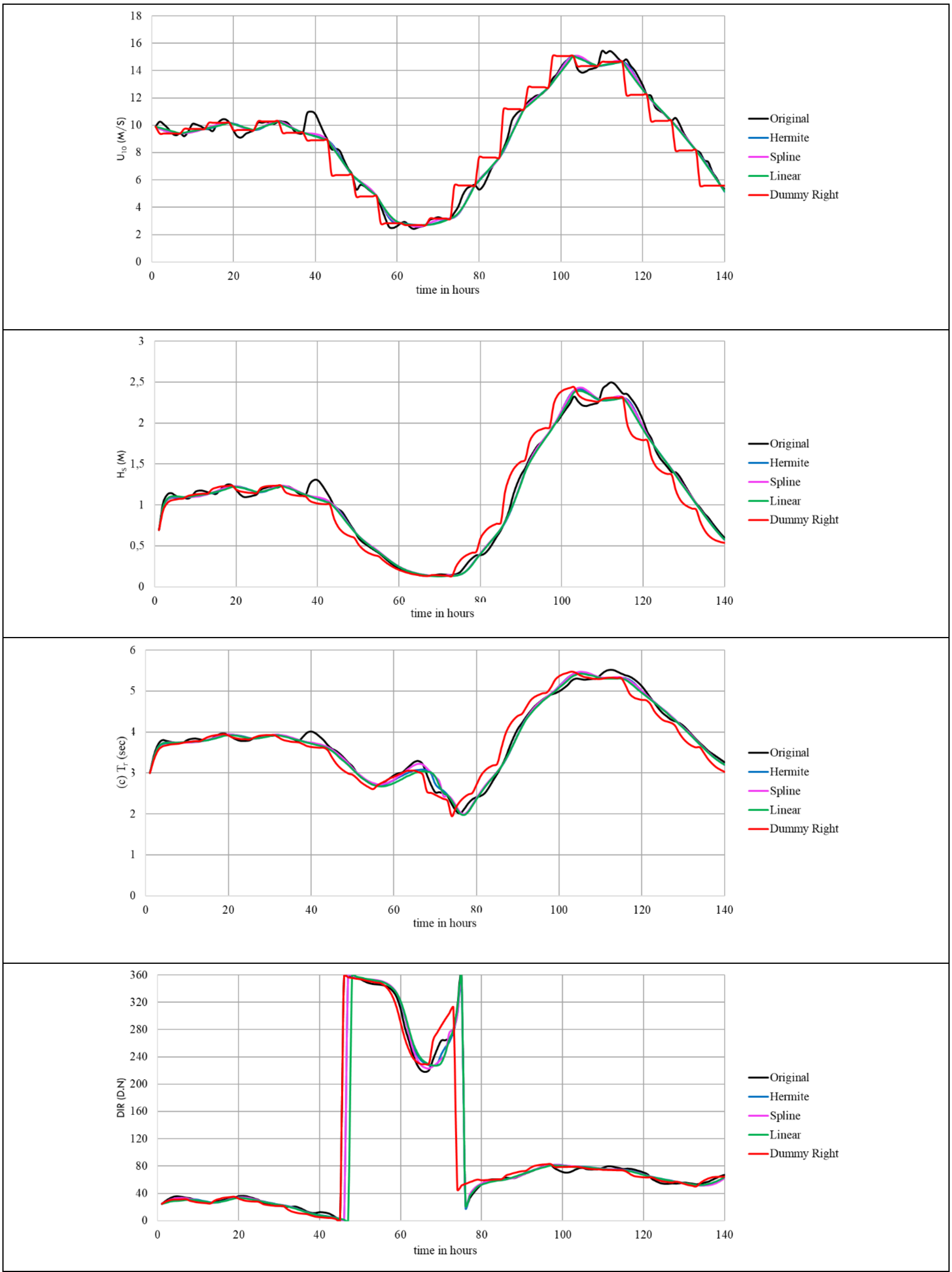


Figure A.70. Wave Analysis of Point N_3

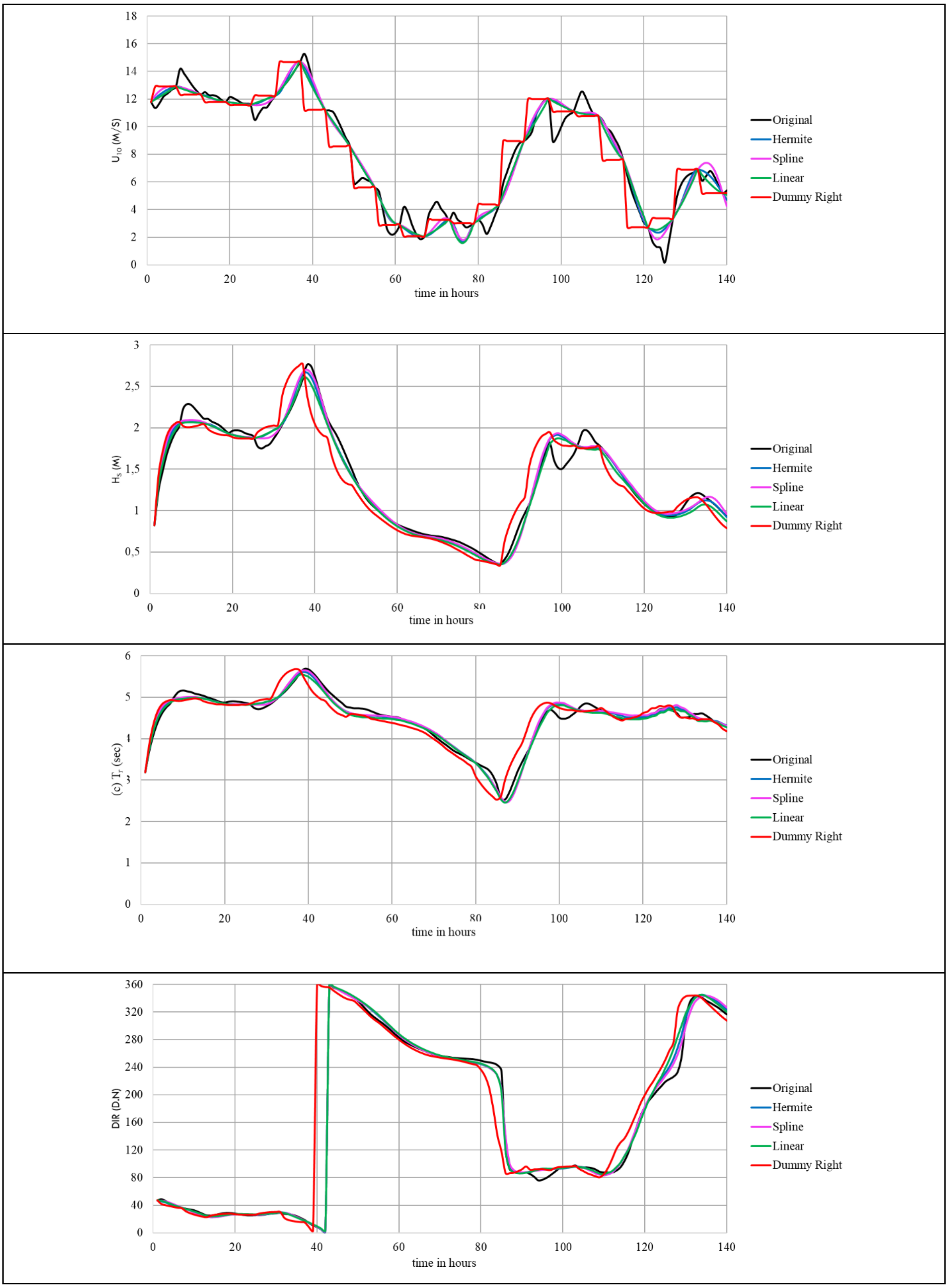


Figure A.71. Wave Analysis of Point N_4

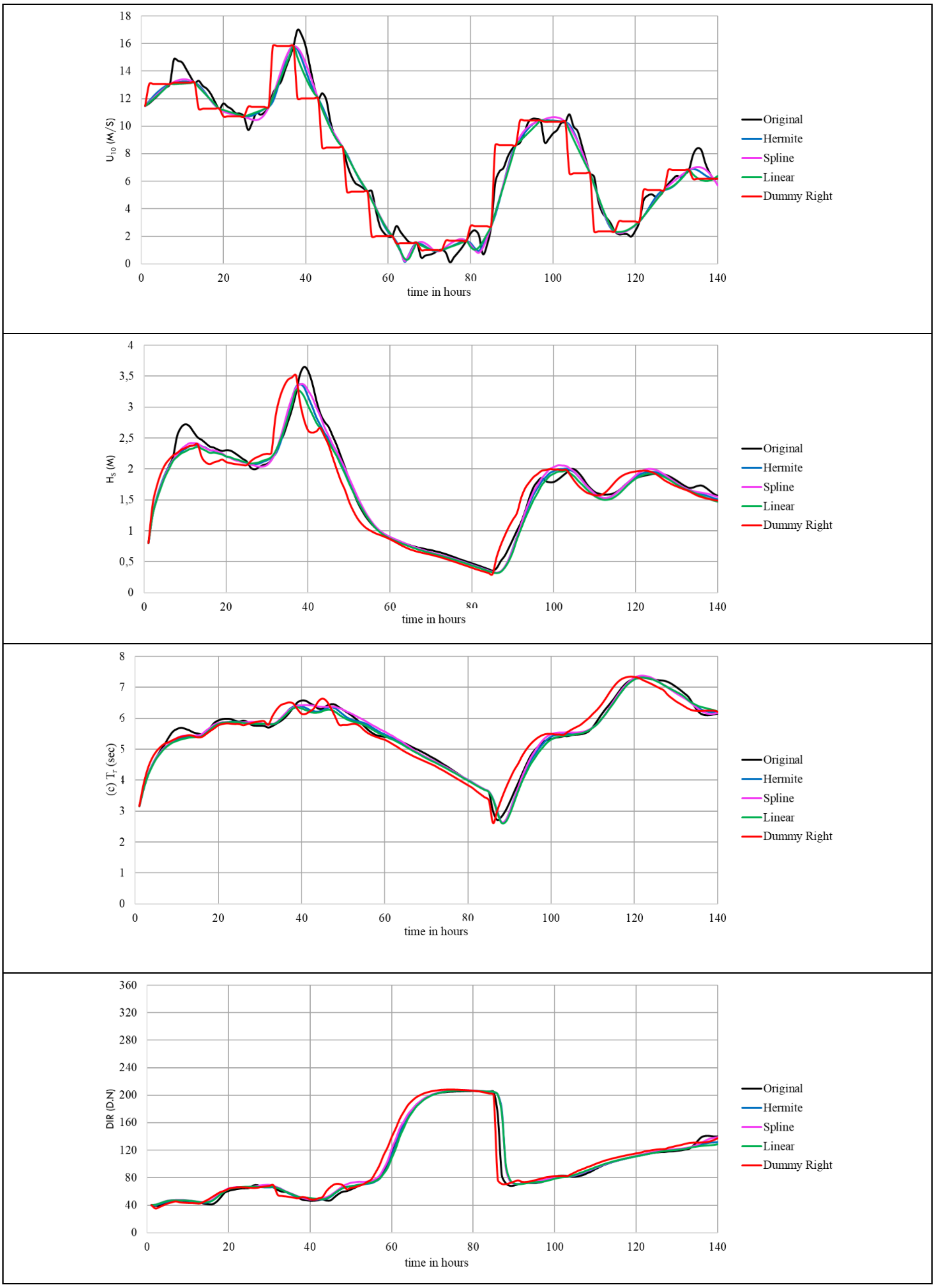


Figure A.72. Wave Analysis of Point N_5

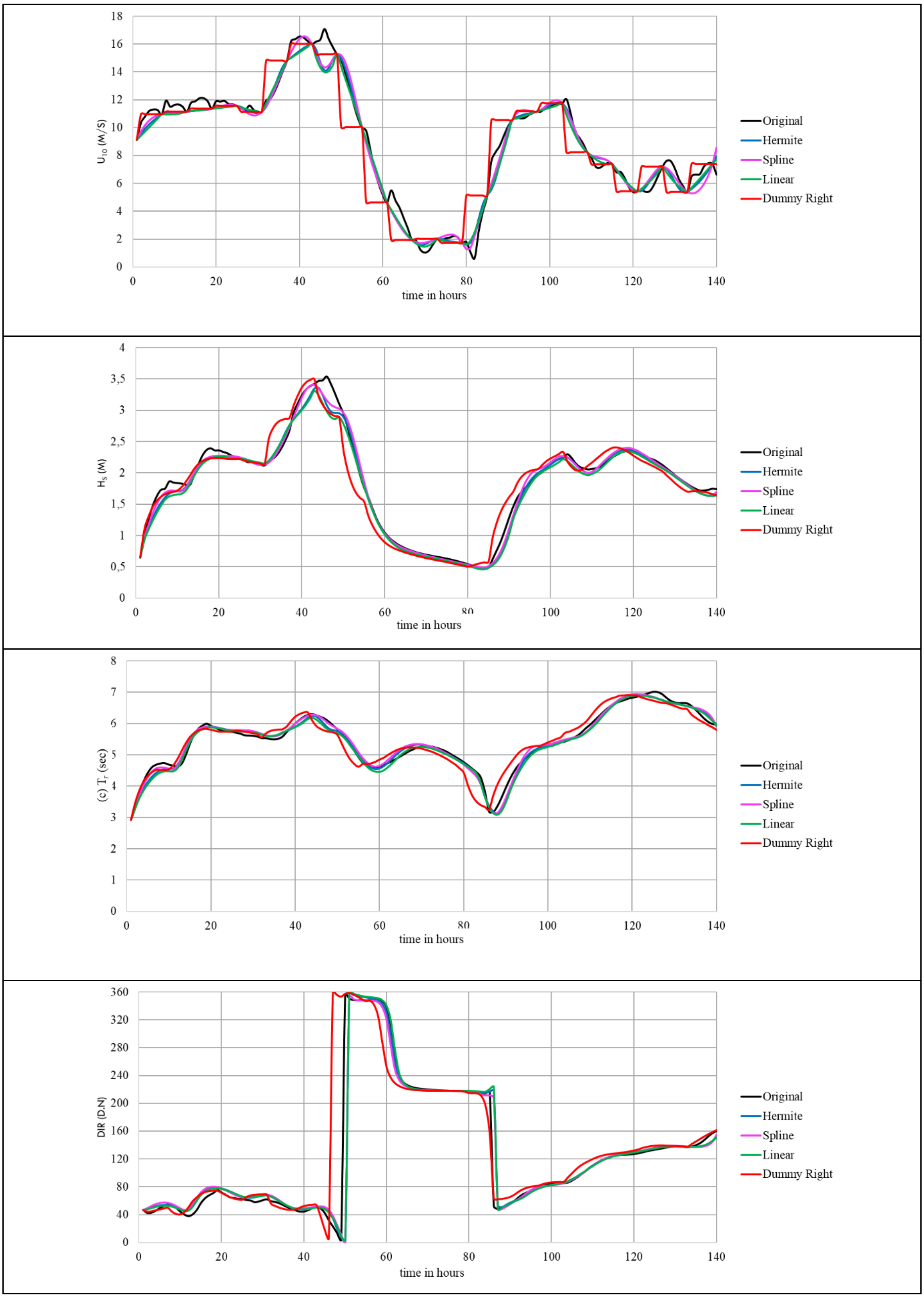


Figure A.73. Wave Analysis of Point N_6

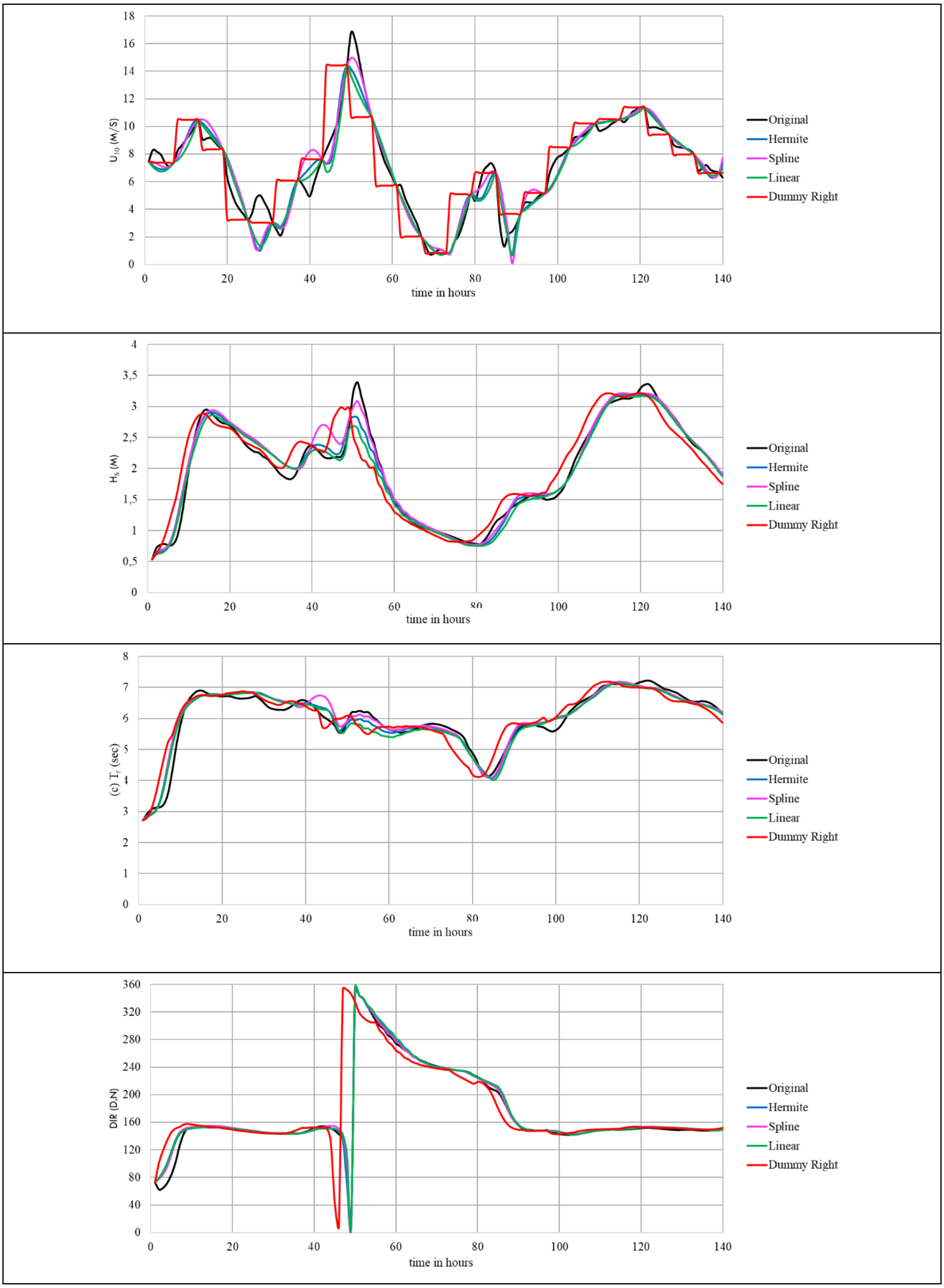


Figure A.74. Wave Analysis of Point N_7

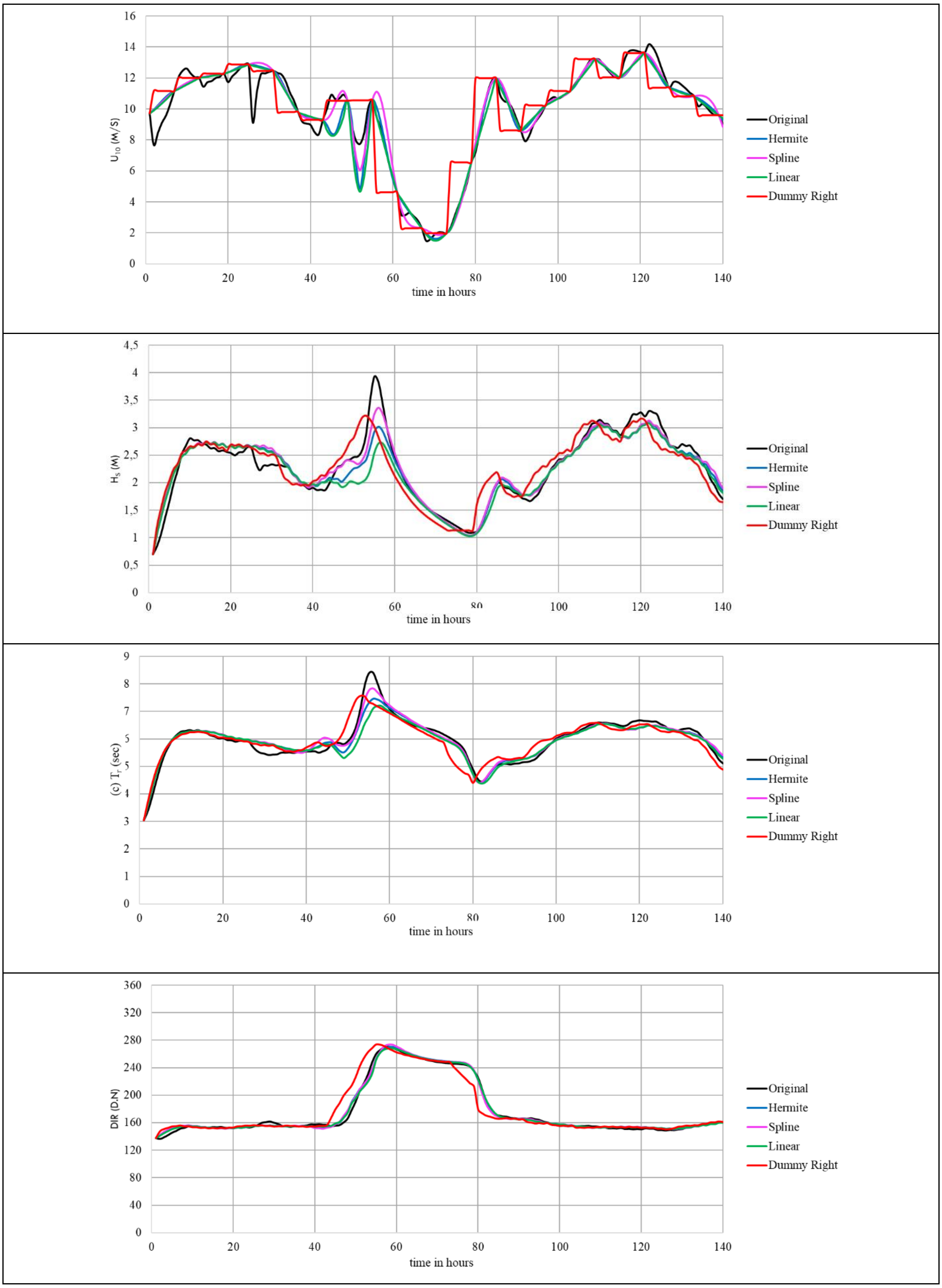


Figure A.75. Wave Analysis of Point N_8