Analysing oceanic spectral wave partitions over time

A bachelor thesis report

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Host Organization:	Aktis Hydraulics
Period:	April - June 2021
Date:	June 25th 2021
Version:	Final

Cover photo: Waves breaking on Senegalese shoreline

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Preface

In front of you lies my thesis, 'Analysing oceanic spectral wave partitions over time', which has been written as a fulfilment of the graduation requirements for the degree of Bachelor of Science at the Faculty of Civil Engineering at the University of Twente. This research is conducted at Aktis Hydraulics and aims to be a contribution to our understanding of the oceans and an advancement in wave predicting technology.

This research would have been impossible without the aid and support of Laury Renac, my supervisor at Aktis Hydraulics, who guided me during this research project. Although the internship was fully carried out online, his availability and direct assistance made it feel like being in the same office. I would like to thank the whole team at Aktis Hydraulics, providing me with this interesting opportunity, making me feel welcome and giving me an insight look at the course of events at an engineering company.

My sincere acknowledgement to Geert Campmans, my university supervisor, who guided me on the academic structure of this thesis. Both his critical feedback and insightful views on the subject helped me to lift this research to a higher level.

Finally, I would like to thank my parents for their love and support during this research period, and my friends, family and all other people that indirectly were involved in the process.

I hope this research may be interesting for the readers and be beneficial for future researchers.

Enschede, June 25, 2021

Dick Heijboer

Abstract

Oceanic spectral wave partitions are wave groups with similar characteristics. By being able to analyse these wave partitions separately over a period of time, a better base for statistical analyses is created. This is beneficial for the prediction of oceanic behaviour in terms of waves. In this research, the following question is asked; 'What is a suitable method of analysing spectral wave partitions over time?'

A method is developed, which compares wave partitions with other wave partitions occurring in the successive time steps. This comparison is based on their similarity in characteristics. When the deviation in characteristics is smaller than a set threshold, the partitions are paired together. Such a paired group of partitions forms a partition series. All those created partition series are then visualized, such that the user can decide on which of those partition series to merge. Those merged partition series will then form partition types. This enables the user to create partition types that are continuous over a period of time. These partition types display the wave systems in effect at a certain location in the ocean.

This method is tested on data sets for a location in the middle of the Pacific Ocean and a location at the Brazilian coast. Based on the partition series selections made by the user, at both locations, multiple partition types are created. These partition types' development over time is visualized, revealing independent partitions which can be individually and continuously analysed over the full time series. This proves this method to be an answer to the research question asked.

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Roman Symbols

Symbol	Quantity or Parameter	Units
$\mathrm{d}t_{\mathrm{max}}$	Maximum number of time steps checked for partition pairing	hours
f	Wave frequency	hertz
H_s	Significant wave height	m
$r_{t,p}$	Normalized radius for partition p at time t	-
S	Spectral energy density matrix	$\mathrm{m}^2\mathrm{s}\ \mathrm{rad}^{-1}$
T	Wave period	s
T_p	Peak wave period	s
t	Time	hours
$z_{t,p}$	Normalized wave height for partition p at time t	-

Greek Symbols

Symbol	Quantity or Parameter	Units
$\delta_{(t,p),(nt,np)}$	Difference between partition p at time t and partition np at time nt	%
δ_{max}	Maximum allowed partition difference	%
θ_m	Mean wave direction	rad
$\varphi_{t,p}$	Normalized direction for partition p at time t	-

1 | Introduction

1.1 Essence of Wave Partition Analysis

The art of predicting ocean behaviour has rapidly advanced over the years (Pinardi et al., 2017). Understanding the ocean and being able to foresee ocean waves such as wind seas and swells is essential when predicting floods and storms. This research aims to contribute to our understanding of the oceans by providing an effective method to individually analyse wave partitions, such as swells and wind seas, at a certain location, over time. Wave partitions are defined as a group of waves with similar characteristics, such as propagation direction, wave period or wave height. By being able to evaluate these wave partitions independently, a better foundation for statistical analysis and extreme value analysis of these wave partitions is formed. This has a wide range of practical purposes, such as coastal infrastructure design, offshore operations and construction, open ocean transhipment and other engineering or research applications.

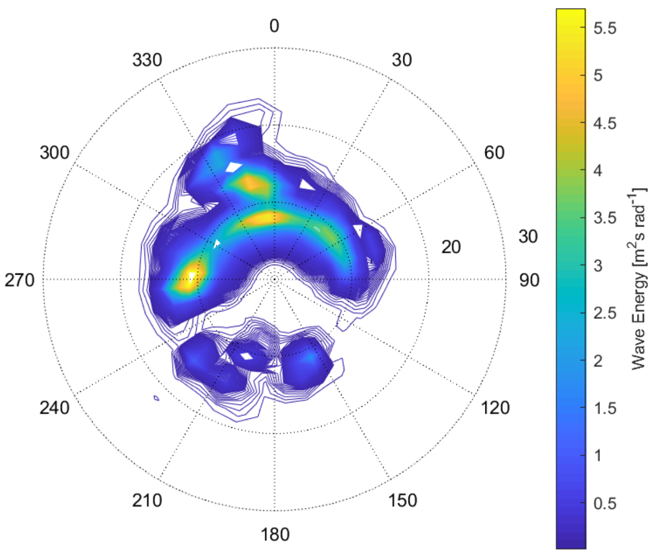


Figure 1.1: Example of a 2D wave spectrum, displaying the wave energy density in terms of wave period and propagation direction

1.2 2D Wave Spectra and Wave Partitions

An accurate way of representing waves is with a 2D wave spectrum. A 2D wave spectrum displays the energy density in terms of propagation direction and frequency at a certain location in the ocean, at a point in time (Bidlot, 2016). This data can be gathered by measurement buoys measuring wave occurrence or be generated by hindcast models. This spectrum is described by a spectral matrix $S(f, \theta)$ where f is the wave frequency in Hertz and θ the propagation direction in Degrees. Regularly, the wave frequency is interchanged with the wave period ($T = 1/f$) for readability.

An example of such a wave spectrum can be seen in Figure 1.1. The angle represents the propagation direction in nautical convention and the radial axis shows the wave period. The wave energy density is expressed in the change of colour. On such a 2D wave spectrum, energy peaks can be identified as lighter coloured areas. Figure 1.1 shows multiple energy peaks at the time of measurement, for example, one with an approximate period 10 seconds, coming from a direction of 270 degrees. This implies that multiple waves with these characteristics were observed at time of measurement. Those peaks are called wave partitions. Portilla et al. (2009) describes wave partitions as the identified subsets of the wave spectra that contain a single wave system. The process of extracting these partitions from the wave spectrum used for this research is spectral partitioning.

As described by Hanson and Phillips (2001), spectral partitioning facilitates the division of the wave energy spectrum into distinct subsets that represent individual wind sea and swell wave systems. Each system can subsequently be described by a set of variables. The first step [1] is to go through the spectral matrix $S(f, \theta)$ and identify the paths of the steepest ascent leading to each peak or local energy maximum. All paths leading to the same peak are grouped and numbered, as shown in Figure 1.2. The figure displays the spectral matrix, where a higher value indicates a higher energy density.

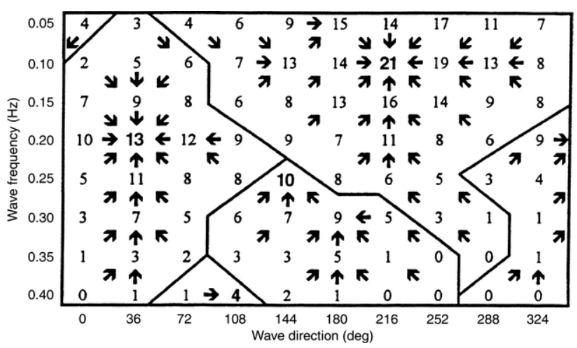


Figure 1.2: Identification of peaks in the wave spectrum, as the first step of the spectral partitioning method (Hanson and Phillips, 2001)

The second step [2] in this process is to identify the wind sea peaks and to combine them. Wind seas can be recognized by their short wave period, and by comparing the wind seas with the prevailing wind at the moment and location of measurement. Thirdly [3], closely related swell peaks or sub-peaks belonging to a bigger peak are merged. Finally [4], peaks with an energy level below a certain threshold are considered as noise and combined with the other peaks. With those peaks established, the characteristics describing the peaks can be obtained, such as the mean or peak direction, mean or peak period or significant wave height and spreading of those variables. The defined peaks are called partitions. The inner workings of the wind seas and swell merging processes and calculation of the descriptive parameters are outside of the scope of this research due to the confidential nature of those methods developed at Aktis Hydraulics. Figure 1.3 shows the earlier displayed spectrum with the partitions identified and numbered. On this example spectrum, five partitions are identified.

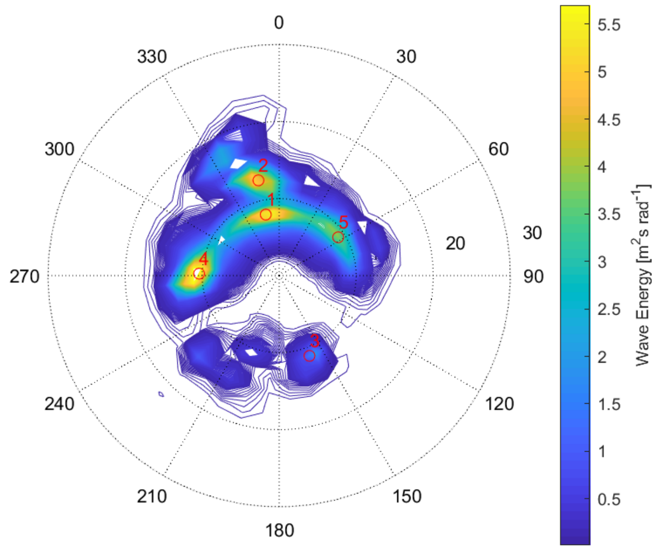


Figure 1.3: The example 2D wave spectrum (same as Figure 1.1) with five partitions identified using the spectral partitioning method

1.3 Current Method of Wave Partition Analysis

Efforts have already been made to individually assess wave partitions over time, however it has drawbacks. The method in use at Aktis Hydraulics at the time of writing is to let the user divide the wave spectrum into multiple sections. This is done by choosing coordinates on the spectrum $V(\theta, T)$ indicating the vertexes of a polygon. For all the created polygons and the empty area outside of the polygons, partitions will be constructed and their descriptive parameters calculated. Those partitions are called partition types. Because those sections are not changing over time, the same partition types are created for every time step, creating a fairly continuous time series for every partition type that is created. An example of this polygon selection on the spectrum is given in Figure 1.4, where the user has selected three polygons and thus four partition types are created, with the fourth one being the remainder of the spectrum.

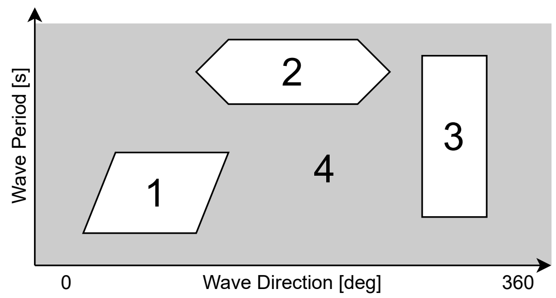


Figure 1.4: Current method of wave partition analysis where the user has defined three spectral sections to track

To guide the user on which sections of the spectrum to select, first, the partitions are calculated using the method described in Section 1.2. All those partitions in all the time steps analysed are plotted on the spectrum using the peak period and peak direction describing the partitions. When partition groups are formed or patterns show up, the sections could be selected such that those partition groups will form one partition type. The first disadvantage of this method is that two or more possible unique partitions lying in the same spectral section will be merged to one partition type, whilst they should be analysed independently. Secondly, when the direction or period of a partition moves over time such that it does not fall within its spectral section anymore, it is merged to another spectral section and becomes another partition type, creating a discontinuity in the partition type data.

1.4 Research Question

In this research a method is worked out where spectral wave partitions and its characteristics can individually and continuously be analysed over full time series. This is done by answering the following research question:

What is a suitable method of analysing spectral wave partitions over time?

1.5 Report Structure

In the following chapter [2] the Method will be elaborated. The method consists of multiple processes. First, an overview of the processes involved with their inputs and outputs will be given, afterwards, the processes will be explained individually. In the next chapter [3] the Results of this method will be displayed for two distinct locations. Furthermore, the effects of variation in the input variables to this method will be visualized. In the Discussion [4] the results will be critically analysed, the limitations of the method discussed and recommendations be made. Finally, in the Conclusion [6], the prior stated research question will be answered.

2 Method

2.1 Overview

In this chapter the developed method will be explained. The process can be divided into multiple steps, as displayed in Figure 2.1. In this section an overview of the different processes will be given, describing the inputs and outputs. In the next sections, the processes will be explained.

The first step of the process is the 'Spectra Splitter'. This process is not developed during this research and is described in Section 1.2, explaining how the peaks are identified in the 2D wave spectrum and merged if needed, creating several partitions at every time step. These single partitions are paired with closely related partitions in subsequent time steps in the 'Partition Matcher' process. These time series containing matched partitions are defined as partition series. However, those partition series are often incomplete and multiple partitions will still not be matched to any other partitions, creating single time step partition series.

Therefore, in the next process, the 'Type Assigner', the partition series are visualized such that the user can combine partition series to form types. The final 'Type Creator' process merges the partitions chosen by the user to form partition types. This creates data time series for the partition types chosen by the user.

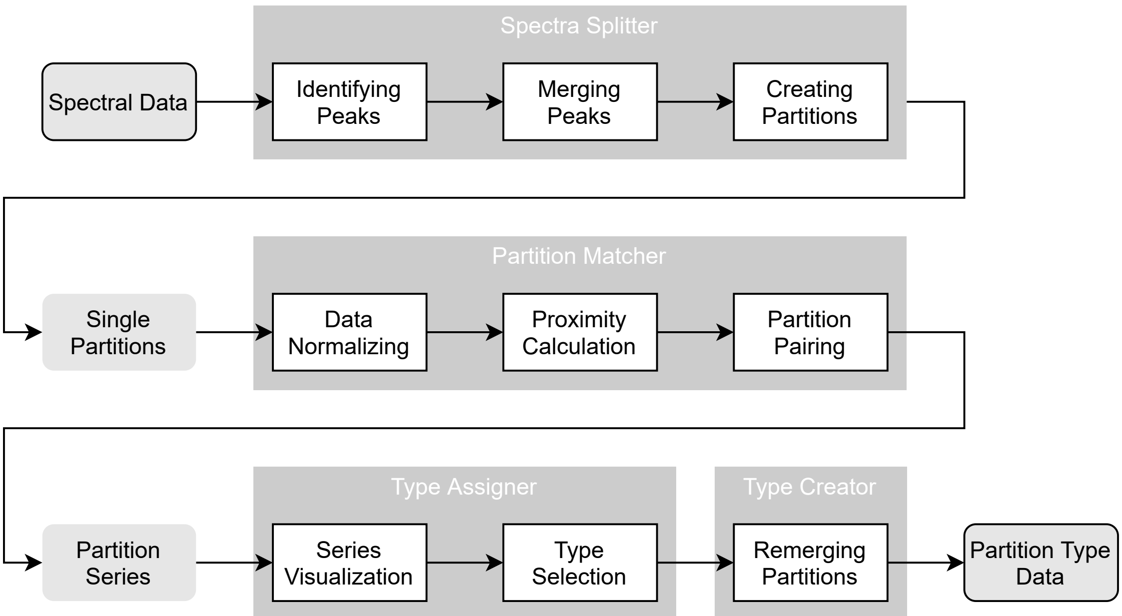


Figure 2.1: Process flowchart

2.2 Partition Matcher

The Partition Matcher process can be split up into three sub-processes. In the first sub-process, the data with which the partitions will be compared is normalized such that various variables can be used together in the comparing process. Secondly, the partitions proximities will be calculated using these normalized values. In the final sub-process, the partitions are paired if the proximity is below a deviation threshold.

Name	Symbol	Range	Unit	Normalized Symbol
Peak Period	T_p	$[0, \max T_p]$	s	r
Mean Wave Direction	θ_m	$[-\frac{1}{2}\pi, \frac{3}{2}\pi]$	rad	φ
Significant Wave height	H_s	$[0, \max H_s]$	m	z

Table 2.1: Variables used for calculating the proximities of the partitions

2.2.1 Data Normalizing

The variables describing the partitions that are used for the comparison can be found in Table 2.1. In order to effectively combine the multiple variables, the variables have to be normalized such that the weight of each variable is equal. The variables r, φ and z are set to be the normalized variables of the peak period, mean wave direction and significant wave height respectively with a range from 0 to 1.

Peak Period and Significant Wave Height

The peak period of a partition p at time step t is normalized by dividing it with the maximum peak period value found in all partitions through all time steps. This results in a normalized period variable with a range between 0 and 1, where the maximum value of the data set is 1. The same is done to normalize the significant wave height. Therefore, the normalized values for the period and wave height at time step t for partition p can be written as such:

$$r_{(t,p)} = \frac{T_{p(t,p)}}{\max T_p} \tag{2.1}$$

$$z_{t,p} = \frac{H_{s(t,p)}}{\max H_s} \tag{2.2}$$

Mean Wave Direction

In the data used the range of the mean wave directions are from $-\pi/2$ to $3\pi/2$. The first step in normalizing the direction is adding $\pi/2$ to the heading to create a range between 0 and 2π. Dividing this value by 2π, results in a variable with a range between 0 and 1, for partition p at time step t.

$$\alpha_{(t,p)} = (\frac{1}{2}\pi + \theta_{m(t,p)})\frac{1}{2\pi} \tag{2.3}$$

To be able to match peaks that move from the $-\pi/2$ to $3\pi/2$ side of the wave spectrum or the other way around, a vector of normalized angles is created with a difference in one rotation (2π) subtracted and added to the angle.

$$\varphi_{t,p} = \begin{bmatrix} \alpha_{t,p} - 1 & \alpha_{t,p} & \alpha_{t,p} + 1 \end{bmatrix} \tag{2.4}$$

2.2.2 Proximity Calculation

The next sub-process is to calculate the proximity of all partitions occurring at time step t to all partitions occurring in time step $t + \mathrm{d}t$. This proximity is expressed in the difference in normalized period, direction and wave height.

Peak Period and Significant Wave Height Difference

The difference in period is calculated by subtracting the normalized partitions at time t to the normalized partitions at time is $t+\mathrm{d}t$, creating a $np \times np$ matrix, where np is the number of partitions identified per time step. The same can be done for the difference in wave height.

$$\Delta r_{t,t+\mathrm{d}t} = \begin{bmatrix} |r_{t,1} - r_{t+\mathrm{d}t,1}| & |r_{t,2} - r_{t+\mathrm{d}t,1}| & \cdots & |r_{t,np} - r_{t+\mathrm{d}t,1}| \\ |r_{t,1} - r_{t+\mathrm{d}t,2}| & |r_{t,2} - r_{t+\mathrm{d}t,2}| & \cdots & |r_{t,np} - r_{t+\mathrm{d}t,2}| \\ \vdots & \vdots & \ddots & \vdots \\ |r_{t,1} - r_{t+\mathrm{d}t,np}| & |r_{t,2} - r_{t+\mathrm{d}t,np}| & \cdots & |r_{t,np} - r_{t+\mathrm{d}t,np}| \end{bmatrix} \tag{2.5}$$

$$\Delta z_{t,t+\mathrm{d}t} = \begin{bmatrix} |z_{t,1} - z_{t+\mathrm{d}t,1}| & |z_{t,2} - z_{t+\mathrm{d}t,1}| & \cdots & |z_{t,np} - z_{t+\mathrm{d}t,1}| \\ |z_{t,1} - z_{t+\mathrm{d}t,2}| & |z_{t,2} - z_{t+\mathrm{d}t,2}| & \cdots & |z_{t,np} - z_{t+\mathrm{d}t,2}| \\ \vdots & \vdots & \ddots & \vdots \\ |z_{t,1} - z_{t+\mathrm{d}t,np}| & |z_{t,2} - z_{t+\mathrm{d}t,np}| & \cdots & |z_{t,np} - z_{t+\mathrm{d}t,np}| \end{bmatrix} \tag{2.6}$$

Mean Direction Difference

As described in Section 2.2.1, the normalized mean direction for partition $\varphi_{t,p}$ is expressed as a vector (Equation 2.4), containing the angle, the angle one rotation back and one rotation forward. The difference in direction between $\varphi_{t,p}$ and $\varphi_{t+\mathrm{d}t,p}$ is calculated as the smallest of the three values. Because $\boldsymbol{\varphi}_{t,p}$ is expressed as a vector, there is no need for $\varphi_{t+\mathrm{d}t,p}$ to be a vector as well.

$$\Delta\varphi_{t,t+\mathrm{d}t} = \begin{bmatrix} \min|\boldsymbol{\varphi}_{t,1} - \varphi_{t+\mathrm{d}t,1}| & \min|\boldsymbol{\varphi}_{t,2} - \varphi_{t+\mathrm{d}t,1}| & \cdots & \min|\boldsymbol{\varphi}_{t,np} - \varphi_{t+\mathrm{d}t,1}| \\ \min|\boldsymbol{\varphi}_{t,1} - \varphi_{t+\mathrm{d}t,2}| & \min|\boldsymbol{\varphi}_{t,2} - \varphi_{t+\mathrm{d}t,2}| & \cdots & \min|\boldsymbol{\varphi}_{t,np} - \varphi_{t+\mathrm{d}t,2}| \\ \vdots & \vdots & \ddots & \vdots \\ \min|\boldsymbol{\varphi}_{t,1} - \varphi_{t+\mathrm{d}t,np}| & \min|\boldsymbol{\varphi}_{t,2} - \varphi_{t+\mathrm{d}t,np}| & \cdots & \min|\boldsymbol{\varphi}_{t,np} - \varphi_{t+\mathrm{d}t,np}| \end{bmatrix} \tag{2.7}$$

Proximity Calculation

Using these normalized differences in peak period, mean direction and significant wave height, the proximity of all partitions at time is t relative to the partitions at time is $t + \mathrm{d}t$ can be calculated. To calculate this difference, the following equation is used:

$$\delta_{t,t+\mathrm{d}t} = \frac{1}{\sqrt{3}} \sqrt{\Delta r^2_{t,t+\mathrm{d}t} + \Delta \varphi^2_{t,t+\mathrm{d}t} + \Delta z^2_{t,t+\mathrm{d}t}} \times 100\% \tag{2.8}$$

$$\delta_{t,t+\mathrm{d}t} = \begin{bmatrix} \delta_{1,1} & \delta_{2,1} & \dots & \delta_{np,1} \\ \delta_{1,2} & \delta_{2,2} & \dots & \delta_{np,2} \\ \vdots & \vdots & \ddots & \vdots \\ \delta_{1,np} & \delta_{2,np} & \dots & \delta_{np,np} \end{bmatrix} \tag{2.9}$$

This results in a matrix giving the percentile difference between all partitions in time step t and time step $t + \mathrm{d}t$. A difference of 100% is the theoretical maximum difference two partitions can have and a difference of 0% is a perfect match where the period, direction and wave height will be exactly the same value.

2.2.3 Partition Pairing

To pair the partitions of time step t with the partitions of time step $t+1$, the distance matrix $\delta_{t,t+1}$ is checked for its smallest values. Starting from the smallest value in the matrix, the partitions are matched until the maximum allowable percentile difference is reached. The maximum allowable difference (δ_{max}) is a set percentage indicating the threshold above which a partition will not be matched.

$$\delta_{(t,p),(t+\mathrm{d}t,p)} \leq \delta_{\mathrm{max}} \tag{2.10}$$

If all possible pairs are made, but still partitions at time step t are unmatched, the distance matrix $\delta_{t,t+2}$ comparing the partitions at time step t with the partitions at time step $t + 2$ will be calculated and the process repeated. However, once a partition at time step t is paired to a partition in any time step, it is not allowed to be matched once again in the next time steps. This process is repeated until all partitions in time step t are paired or the maximum number of time steps that are checked ($\mathrm{d}t_{\mathrm{max}}$) is reached.

$$t + \mathrm{d}t \leq \mathrm{d}t_{\mathrm{max}} \tag{2.11}$$

If a partition p at time step t is not paired to any partition in a previous time step, a new partition series is formed. This way, multiple partition series will be created, which are allowed to move over time, as long as their movement is not larger than the allowable difference threshold set.

2.3 Type Assigner

Visualizing the partition series formed in the partition matching process and the user selection of partition types is the next step in the method.

2.3.1 Partition Series Visualization

Visualizing the partition series can be done in multiple ways. For this research, the partition series are visualized using their average location on the 2D wave spectrum. Using the average peak period and average mean direction of a partition series allows to scatter plot all the partition series simultaneously. Note that not the separate partitions are plotted but the partition series.

2.3.2 Partition Type Selection

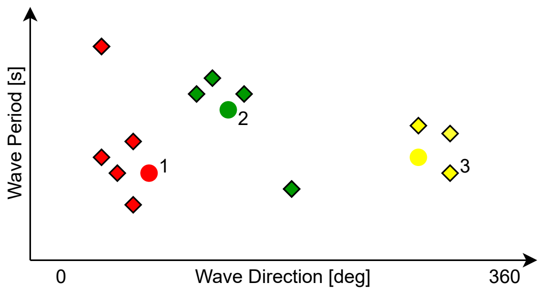
Based on the visualization of the partition series, the user can decide which partition series to merge to form a partition type. Two methods of type selection are developed for this research; point selection and polygon selection.

Point Selection

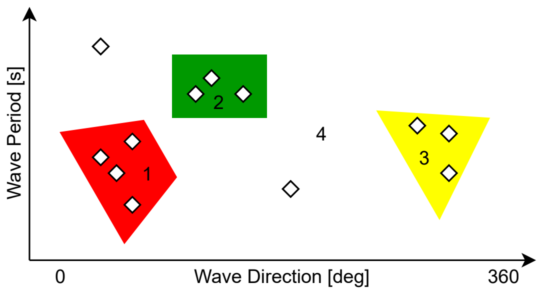
In this method, the user selects several points on the spectrum. For every partition series, the distance between the average location of the partition on the spectrum $\overline{P}(\theta, T)$ and all the selected points on the spectrum $C(\theta, T)$ will be calculated. The partition series will belong to the nearest point. All partitions belonging to a certain point will be assigned to be one partition type.

Polygon Selection

The second developed method is to let the user create polygons by choosing coordinates on the spectrum $V(\theta, T)$, indicating the vertexes of the polygon. All the partition series averages $\overline{P}(\theta, T)$ falling within a certain polygon will be assigned to be one partition type. All partition series not falling within a created polygon will be the final partition type. Examples of both methods are displayed in Figure 2.2.



(a) Point selection creating 3 types



(b) Polygon selection creating 4 types

Figure 2.2: Two partition type selection methods

2.4 Partition Type Creator

The final process in the method is the Partition Type Creator. This process is almost identical to the original Spectra Splitter process as described in Section 1.2, but contains an extra step. Before the partition parameters are calculated, the partitions which are part of series which belong to the same partition type are merged. This is done in a similar way to the wind seas and swells merging.

3 | Results

In this chapter, the results of the method explained in the previous chapter will be displayed. First, the result of two different spectral data sets will be shown, afterwards, the effects of changing the maximum allowed partition difference setting or the maximum number of time steps checked for partition pairing will be discussed.

3.1 Results Method

The spectral data used to present the results is generated by the EMC WaveWatch III® computer model for a location in the middle of the Pacific Ocean and for a location 6 kilometres from the coast of Brazil, Figure 3.1. WaveWatch III is an open ocean model, with a grid resolution of 10 to 50 kilometres. For the coast of Brazil, the SWAN model is used to transform the generated open ocean waves to nearshore waves, with a grid resolution between 2000 to 100 metres.

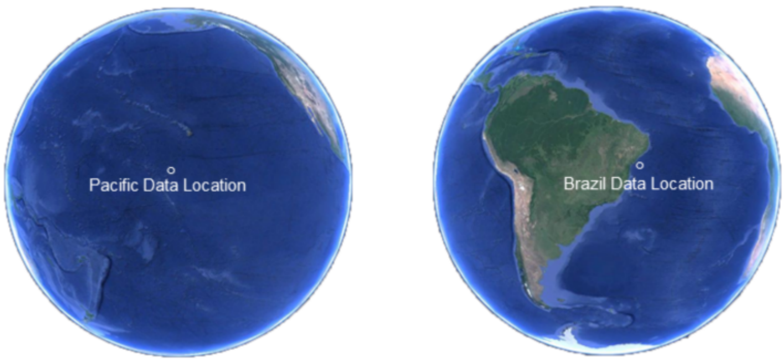


Figure 3.1: Locations for which the spectral data is generated (Google Earth, 2021)

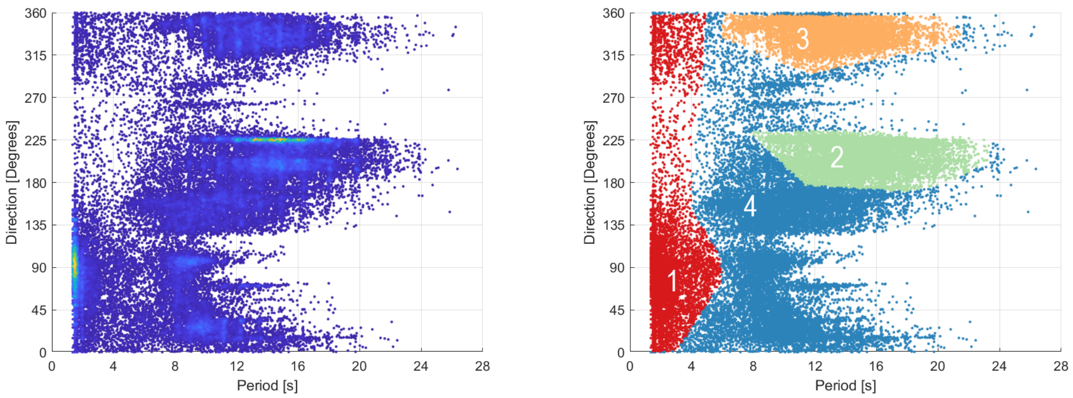
For both locations calculations are executed with a maximum allowed partition difference (δ_{max}) of 8% and a maximum number of time steps checked for partition pairing ($\mathrm{d}t_{\mathrm{max}}$) of 20 hours. The variation in these settings will be discussed in Section 3.2. For creating the Pacific Ocean partition types, the polygon selection method will be used and for the Brazil Coast partition types, the point selection method. The number of time steps and settings used are given in Table 3.1.

Location	Time steps	Time span	δ_{max}	$\mathrm{d}t_{\mathrm{max}}$	Selection method
Pacific	359040	$\approx$ 41 years	8 %	20 hours	Polygon
Brazil	359399	$\approx$ 41 years	8 %	20 hours	Point

Table 3.1: Data used to generate the results and settings applied

3.1.1 Pacific Ocean

The first step in the process is to execute the Spectra Splitter for the spectrum of every time step. Because the location is in the middle of the ocean where many different swell systems occur, the Spectra Splitter is set to be allowed to identify up to ten partitions in the spectrum per time step. Secondly, the partition series are created by matching partitions. The partition series formed are plotted on the spectrum as can be seen in Figure 3.2a. In this case, the user selected three polygons, creating four partitions types, Figure 3.2b. The first type selected are all the short period partitions coming from all directions, often these are wind seas. The second and third partition type have a longer period and are coming from an average direction of 200 and 330 degrees respectively. The last type are all the non-selected partitions. With these polygons created, the partitions are merged such that the partitions, being part of a partition series falling within the same polygon, are merged to be one partition type.



(a) Partition series averages plotted

(b) Polygon selection

Figure 3.2: Three polygons manually selected by the user for the Pacific Ocean data location creating four partition types

Below, the final results of those calculations are displayed. The courses of the partition types are plotted in terms of peak period(Figure 3.3), mean direction(Figure 3.4) and significant wave height(Figure 3.5) for August 2000. These three variables are displayed because they are also used in the proximity calculations, however, any variable calculated by the Spectra Splitter could be used.

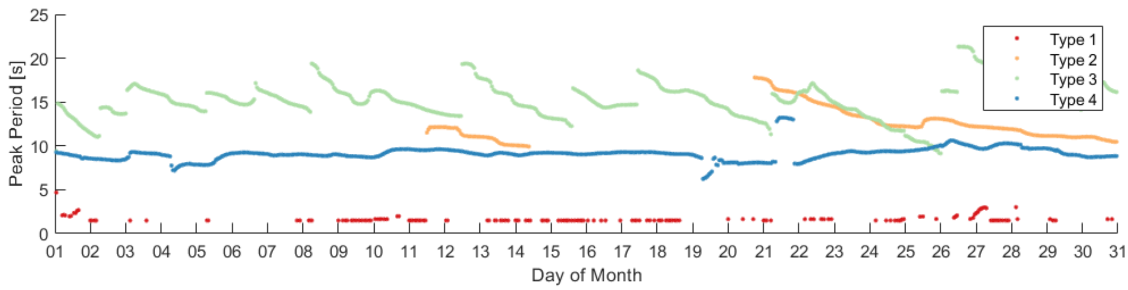


Figure 3.3: Peak period of the partition types for the Pacific Ocean location

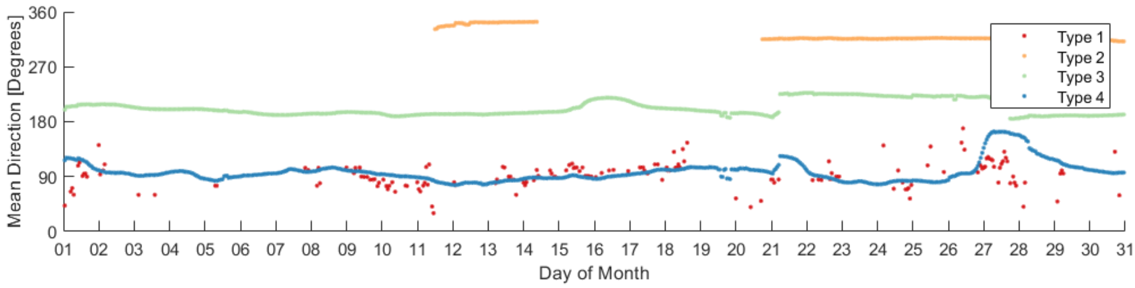


Figure 3.4: Mean direction of the partition types for the Pacific Ocean location

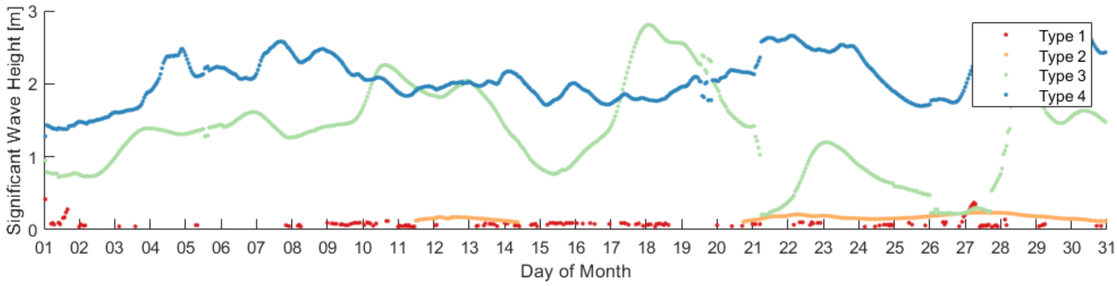
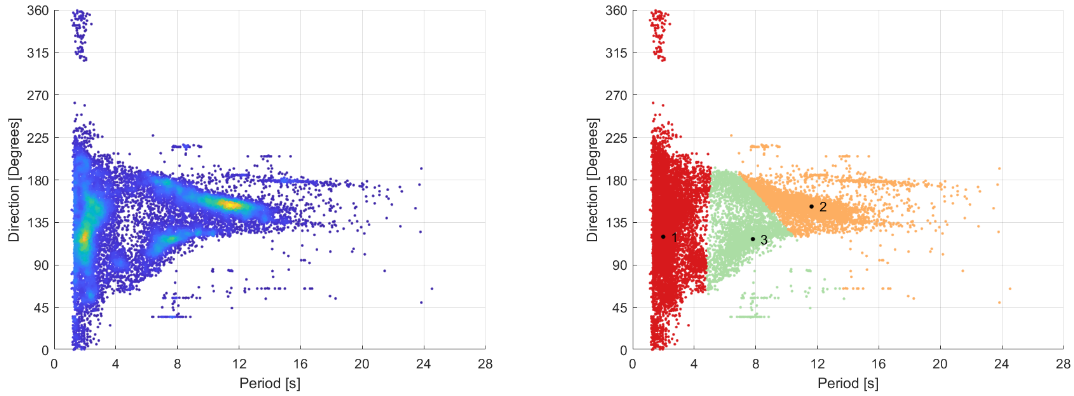


Figure 3.5: Significant wave height of the partition types for the Pacific Ocean location

3.1.2 Brazil Coast

For the location at the Brazilian coast, the mean periods and mean directions of every partition series are plotted on the spectrum shown in Figure 3.6a. The user has selected three points to create three partition types, as shown in Figure 3.6b.



(a) Partition series averages plotted

(b) Point selection

Figure 3.6: Three points manually selected by the user for the Brazil coast data location creating three partition types

Similar to the Pacific Ocean location, the courses of the partition types at the Brazilian coast are plotted in terms of peak period(Figure 3.7), mean direction(Figure 3.8) and significant wave height(Figure 3.9), for the data of August 2010. In Appendix A, for the same Brazil data set, the polygon selection method is used, producing roughly the same results.

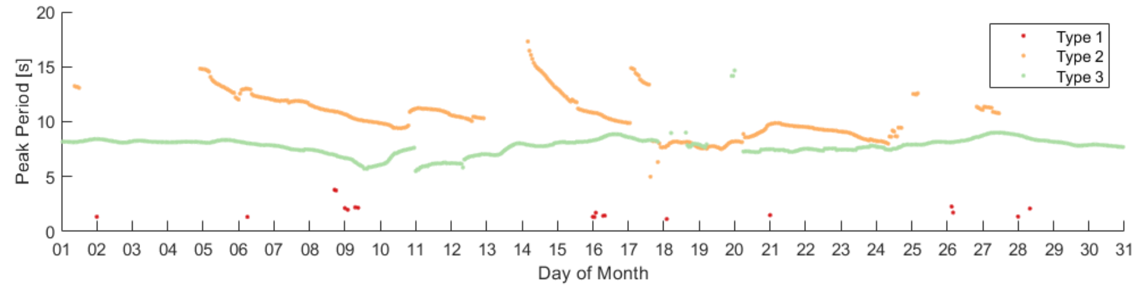


Figure 3.7: Peak period of the partition types for the Brazil coast location

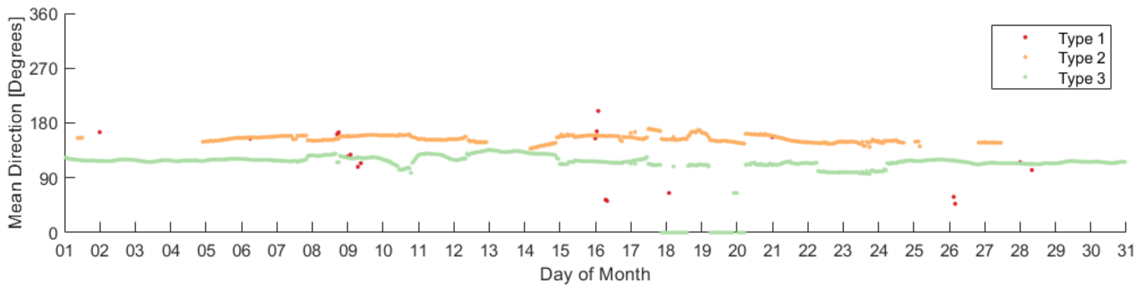


Figure 3.8: Mean direction of the partition types for the Brazil coast location

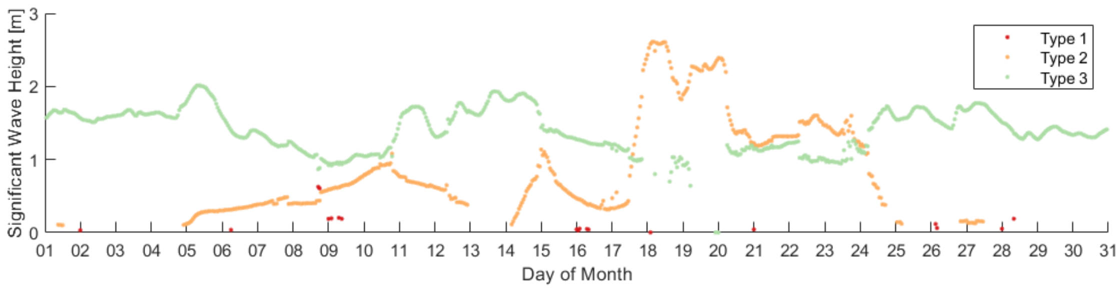


Figure 3.9: Significant wave height of the partition types for the Brazil coast location

3.2 Settings Variations

The developed method includes two adaptable variable inputs, besides the user selection of which partition types to form. These are the maximum allowed partition difference ($\delta_{\max}$) and the maximum number of time steps checked for partition pairing ($\mathrm{d}t_{\max}$).

3.2.1 Maximum Allowed Partition Difference

In Figure 3.10, the variation of allowed partition difference versus the relative number of partition series created is plotted. With a very tight allowable partition difference, almost no partitions can be matched such that the non-paired partitions will become single time step partition series. Therefore, the stricter the matching criterion, the higher the relative number of partition series is. As the allowable partition difference increases, the number of partition series decreases because more partitions can be matched to be one series. With an even further increase of the allowable partition difference, the relative number of partitions measured flatten out, indicating that almost no partitions differ close to as much as the theoretical maximum difference. If the maximum allowed partition difference gets below approximately 7 per cent, the relative number of partitions measured rapidly increases. Therefore, an allowable difference between 5 and 10 per cent is advised.

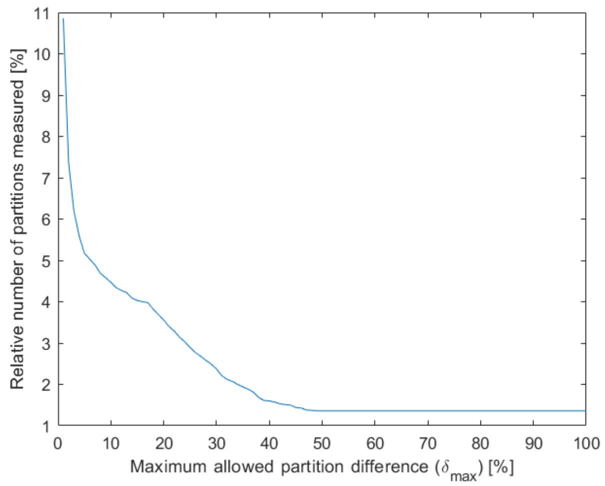


Figure 3.10: Maximum allowed partition difference versus the relative number of partitions measured

3.2.2 Maximum Number of Time Steps Checked

Similarly to the maximum allowed partition difference input setting, the maximum number of time steps checked ($\mathrm{d}t_{\mathrm{max}}$), from 1 to 100 time steps, is plotted against the relative number of partitions created, Figure 3.11. Similar behaviour is observed, as the number of time steps checked increases, more partitions can be matched to a partition series, creating fewer partition series in total. However, calculation times also increase with the increase of time steps. Taking this into consideration, a maximum number of 20 time steps is used to produce the results shown before.

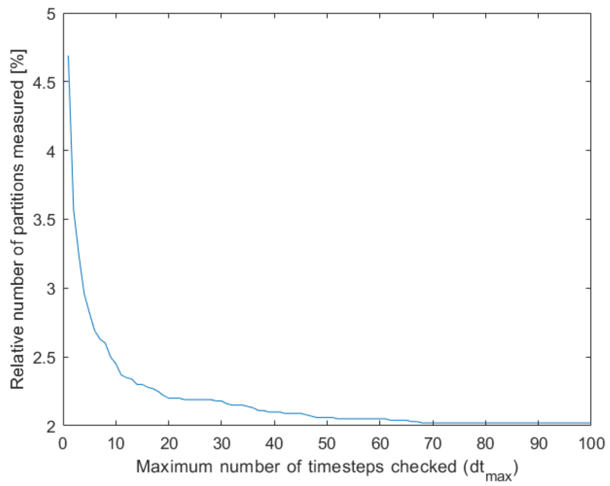


Figure 3.11: Maximum number of time steps checked versus the relative number of partitions measured

4 Discussion

In this chapter, the results shown will be critically discussed and elaborated, method limitations exposed and recommendations for further development or improvements for the current method given.

4.1 Results Discussion

From the visualizations of the partitions types at the Pacific Ocean location and the Brazilian coast, multiple remarks can be made. Evident is that for both locations multiple unique partition types are created, showed by their distinction in peak period, mean direction and significant wave height.

For both the Pacific and Brazil location, the first partition type was selected to have a short wave period. Often these short period partitions are caused by the local prevailing wind. This is visible in the average partition series plot for the Brazil coastline (Figure 3.6a), where only the short period partitions are coming from all directions, as at a coastal location swells do not arrive from the inland direction. These wind partition types occur occasionally on the spectrum and show as expected a low wave height, a short wave period and varying directions. Because the swells are coming from a smaller range of directions at coastal locations, fewer different partitions are measured at coastal environments. Therefore, for the Brazil coastal location, only three partitions are selected.

Partition type two and three at both locations are swells with a higher peak period than partition type one. However, partition type two at the Pacific location has a low significant wave height such that the energy level is for some time steps too low to be seen by the Spectra Splitter as a separate partition and is merged to another partition, as described in Section 1.2. This causes gaps in the time series.

Furthermore, although partition type four at the Pacific Ocean location are all the non-selected partitions merged together, as can be seen in Figure 3.2b, it still produces a relatively stable and continuous time series. This is because a lot of partition types are not selected such that the majority of partition series falls within that type, creating an averaged partition type for the spectrum.

As Appendix A shows, in the case of the Brazil data set, the difference in results by the point selection made by the user and the polygon selection is minimal. Although the results are highly dependent of which partitions are combined to form a type, both methods could be used to roughly produce the same results.

Finally, the behaviour of the peak period of partition type three at the Pacific Ocean location shows a repeating pattern of descending periods spanning multiple days. This is a sign of distant storms coming closer to the location of interest. For long distant swells, the longer period waves travel faster so they tend to arrive earlier at the location of measurement. Although the type is not continuous in terms of period, it is mostly continuous in terms of mean direction and significant wave height.

4.2 Method Limitations

Even though the results show independent partition types developing over time, gaps in the time series are observed. When this happens, no partitions of that particular partition type are generated by the Spectra Splitter for that time step. This can happen because of incorrect peak merging, a peak energy below the threshold or the actual absence of a peak. As a consequence, it is not always possible to consistently create fully continuous time series without any gaps over a longer period of time.

Furthermore, because a big part of the result is dependent on the type selection, on both the placement of the polygons or points and the number of types. This type selection step should be executed carefully with expertise. Random partition type selection will result in meaningless outcomes.

4.3 Recommendations

Because the Spectra Splitter process is a separate process developed with different aims as to how it is used in this method, the remerging of partitions could be improved. This improvement could be done by developing a method for recognizing the peaks on the spectrum that are part of a partition type before they are merged to other peaks or are removed due to their low energy levels. This could potentially result in a more continuous time series of partition types, without or with significantly fewer gaps.

In the current method, for letting the user decide on which partition series to group to form partition types, the average peak period and average mean direction of all the partition series are plotted, described in Section 2.3.1. However, those average values are solely one way of representing the partition series. Different variables could be used to show the behaviour of the partition series such as the significant wave height, or any partition variable that can be calculated by the Spectra Splitter. Furthermore, the range or spreading of the partition series could also be displayed. For instance, the user might want to group partitions that move from one direction to another. This movement cannot be well visualized using average values. Finally, a method to automatically create partition series could be created which can compare and group partition series based on a wide set of descriptive variables.

5 Conclusion

In this thesis, the following research question is asked: ‘What is a suitable method of analysing spectral wave partitions over time?’

This research showed that a suitable way of analysing wave partitions over time is by pairing the partitions identified in the 2D wave spectrum and visualizing the paired partition series, such that the user can select which kind of partition types to create. By merging partition series belonging to the selected types, partition types traceable for the complete time series are created. The method developed was tested for a location in the middle of the Pacific Ocean and a location at the coast of Brazil, and independent time series were created of the partition types selected.

For offshore operations, coastal infrastructure design, open sea transhipment and a wide range of other applications being able to predict waves is essential. This method helps the user to get more homogeneous partition populations, which is useful for performing statistical analyses and extreme value analyses, creating a greater understanding of the wave systems active at the analysed location. With that, hopefully, this research will be a contribution to our comprehension of the oceans.

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Appendix A: Polygon Selection Brazil

To show the difference in results based on the type selection method, next to the point selection method described in Section 3.1.2, also the polygon selection method, with similar selections to the point selection, is used for the Brazil coast location. Note that one more partition type is created using this method, partition type four. This partition type is the combination of all non-selected partition series.

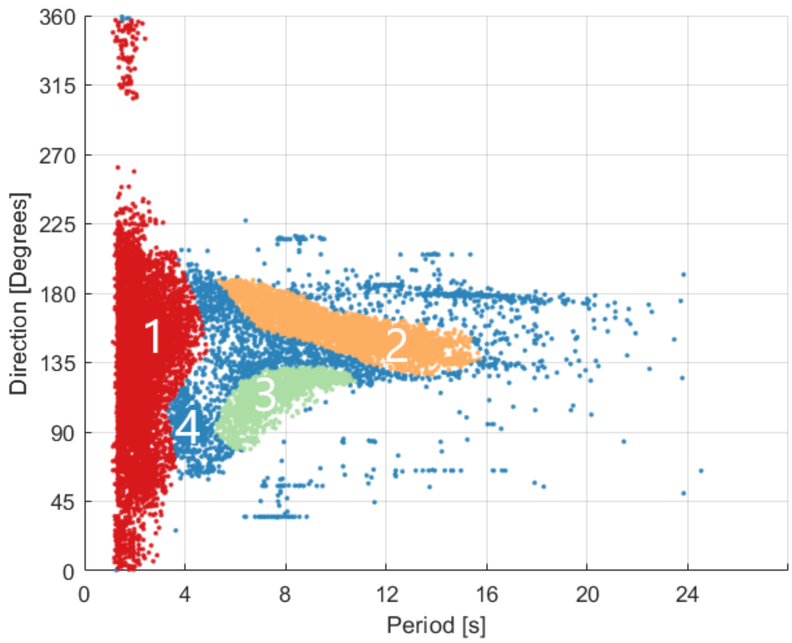

Figure 1: Using polygon selection instead of point selection to create partition types for the Brazil coast data location

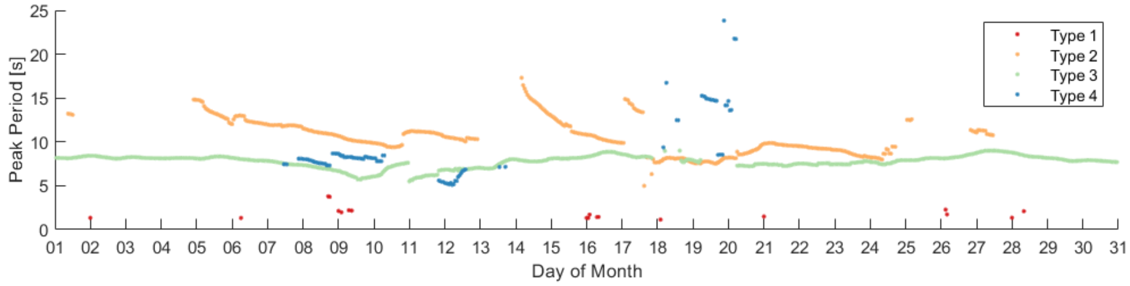

Figure 2: Peak period of the partition types created using polygon selection for the Brazil coast location

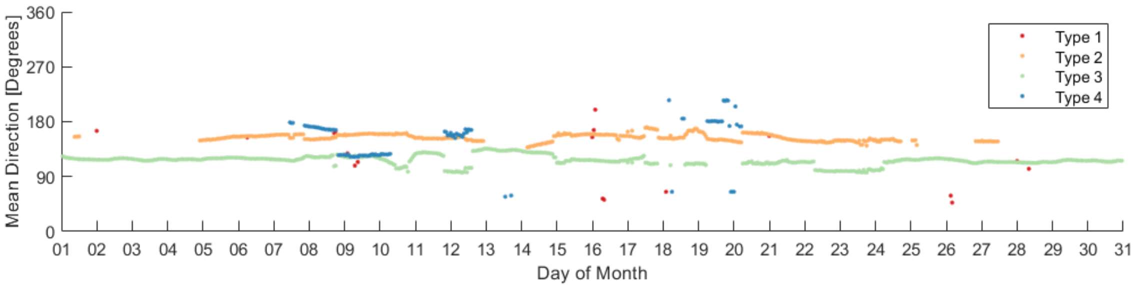

Figure 3: Mean direction of the partition types created using polygon selection for the Brazil coast location

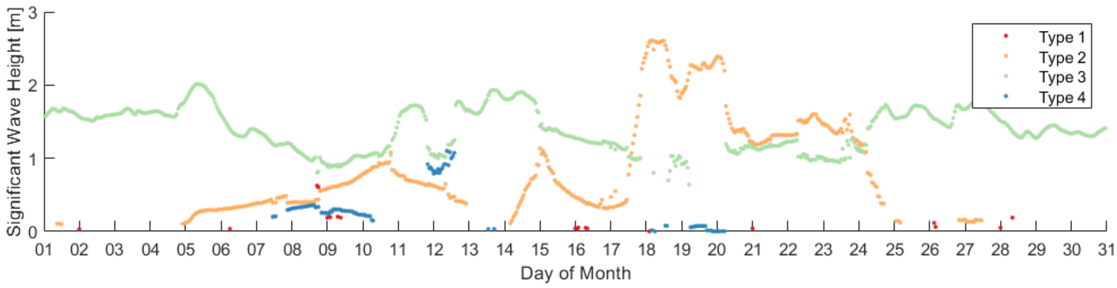

Figure 4: Significant wave height of the partition types created using polygon selection for the Brazil coast location