Physic Project P6

STPI/P6/2022 – 035

Feasibility study for the installation of wave energy convertors in the Channel Sea

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Project aims:

Our project's main purpose is to look into the feasibility of establishing wave energy convertors in the English Channel. First, we wanted to study the advantages and limitations of different types of wave energy convertors that exist today. Then, we looked at the existing projects in the Channel. Only then we could focus on our main goal: gathering wave data from various areas in order to choose the ideal location for installed wave energy convertors .

Keywords: ***Research, renewable energies, English Channel, wave energy, wave energy convertors.***

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1. Introduction

1.2 Abstract

The idea of extracting energy from waves dates back to the early 18th century. In 1973 due to the oil crisis the prices of non-renewable energies suddenly increased. At the same time, scientists realised that with the world's growing population and the exhaustibility of energy resources, we would have to find other ways to produce energy. It was only then that research into renewable energies, including wave energy, really began. And still today, the world-wide demand for electricity is expected to double within the next 20 years. Also considering the climate crisis, it is urgent to succeed in freeing ourselves from fossil fuels and to be able to get energy in a clean way, that is to say without emitting greenhouse gases.

Over the years, innovations such as wind, hydroelectric and solar power have all offered many benefits, and will no doubt continue to support renewable energy initiatives. However, each source also comes with its challenges and downfalls. It turns out that wave energy is still very little exploited, and could be a complementary solution to other renewable energy production systems. That’s why we have focused our research on this new energy.

As we said before, major research and development of wave energy converters began in Great Britain in 1975. These programs were then followed by the Norwegian government. The first prototype was built in 1985 on a coast near Bergen in Norway. The estimated output was between 350kW and 500 kW and it was named Tapchan. Today in the world there are approximately only 1000 WEC.

1.1 Wave energy converters process

Wave energy technologies capture the movement of ocean and sea waves and use it to create energy – usually electricity. The amount of energy created depends on the speed, height, and frequency of the wave. Waves are created by the wind moving over the surface of the ocean, but they continue long after the wind has died down. This complementarity makes wave energy the perfect partner for wind energy, as it extends the power production significantly. When wind blows over the ocean it transmits some of its kinetic energy to the ocean’s surface creating wave energy, a form of energy that contains both kinetic and gravitational potential energy. The power is extracted from the transport of energy by ocean surface waves.

1.2 Distribution of waves

On the map below you can see the average distribution of wave energy, in Kw/m, over a year in the world. It is difficult to find maps showing the wave energy in the Channel sea, so that’s why we will try to estimate this energy in some area of the channel sea, by carrying out the feasibility study.

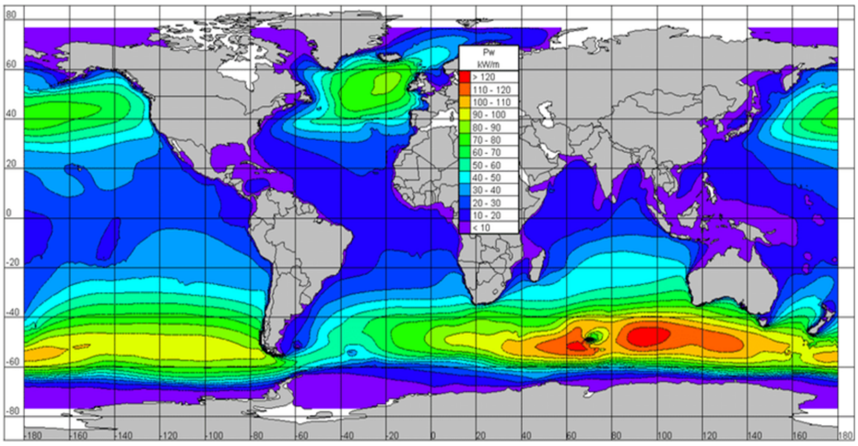


Figure 1 : Global distribution of annual mean wave power [1]

1.3 Wave energy converter technologies

There are various additional ways to differentiate wave energy conversion technologies. They can be classified according to their location (shoreline, near-shore or offshore), their mooring and foundation structures (fixed or floating), their Power take off system, named PTO, (air turbines, hydraulic turbines, hydraulic engines), and the way they convert wave energy (rotation, translation, heaving, surging, pitching).

As a result, wave energy converters can be classified into 4 different types which are :

- The oscillating water column
- The overtopping
- The attenuators
- The point absorber

Each category will be presented in detail in part 3.

2. Work organisation

The choice of this subject was a result of a complicated equation that should consider our schedules which may not be the same even for people from the same specialisation. We didn't know each other at the very first beginning. However, our teacher made it a lot easier by dividing the work into 4 so that we can work individually and in groups. As for Salma, she worked on oscillating water columns, Antoine worked on attenuators, Peiwen and Xinyue worked on point absorbers and Elodie worked on overtoppings. We had meetings each Tuesday at 8 AM with our teacher to make a point over our progress, our questions and our organisation for the following week. We had to prepare a slideshow to present our work. It was really good training for the presentation. So as the subject was a bibliography and a feasibility study, it took place in two phases. First we started with making research about the subject and about each type of device to which we were assigned and every Tuesday we presented our progress to our partners. Then when the bibliography is done, we go through the modelling part. That was based on extracting datas with Matlab and drawing graphs for further explanations of the subject. Indeed, we faced different kinds of problems while carrying out this project. Considering the fact that no one had ever used Matlab before, we took time to get used to the platform and start working on the extraction of datas from the ECMWF website. In spite of that, Mr. ALAMIAN was always there with all ears listening to our matters and looking for solutions to them. Otherwise, everything went well and we can say that it was indeed a good experience. We learned to work as a team despite the language barrier.

3. Work carried out and results

3.1 Oscillating water column

3.1.1 Introduction

In 1947, Yashio Masuda (1925-2009), a Japanese navy officer, designed and installed the first OWC driving an impulse turbine to produce electricity. An OWC is a partially submerged, hollow structure which is open to the sea water below the surface and connects to an air turbine above through a chamber. It uses a large volume of moving water as a piston in a cylinder. Air is forced out of the column as a wave rises and fresh air is drawn in as the wave falls. This movement of air turns a well turbine at the top of the column **(Figure 2,3).** Wave movement creates changes in volume for the air to occupy. This causes pressure differences that the air flow is directed into the Wells turbine chamber.

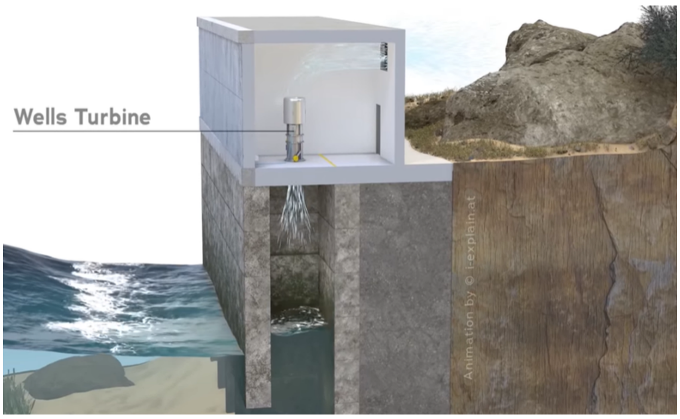


Figure 2 : Oscillating water column [2]

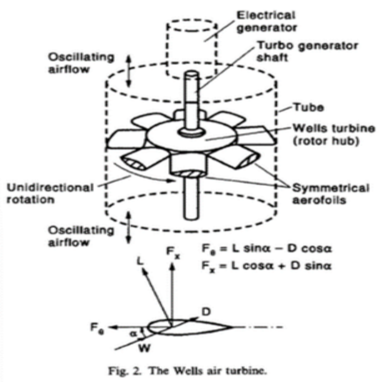


Figure 3 : Wells turbine [3]

The Wells turbine consists of aerofoils whose symmetry directs the air in the same direction creating unidirectional rotation for the oscillating airflow. This allows for the turbine to always power the generator regardless of the direction of airflow.

3.1.2 Advantages / Disadvantages

3.1.2.1 Advantages

The attraction of the OWC stems from its simplicity and for being gases free. On a practical level:

- There are very few moving parts.
- The moving parts are housed outside of the water for a greater lifetime of the material.
- The concept is adaptable and can be used on a range of collector forms situated on the coastline, in the nearshore region or floating offshore
- The use of an air turbine eliminates the need for gearboxes.
- It uses sea space efficiently.
- The well turbine achieves an efficiency between 40 and 70%.

3.1.2.2 Withdraws

- Projects are small so that project costs are disproportionately high
- Small volumes mean high equipment costs
- Weak grids at suitable coastal sites mean high connection charges

3.1.3 Examples

3.1.3.1 Islay LIMPET - Scotland

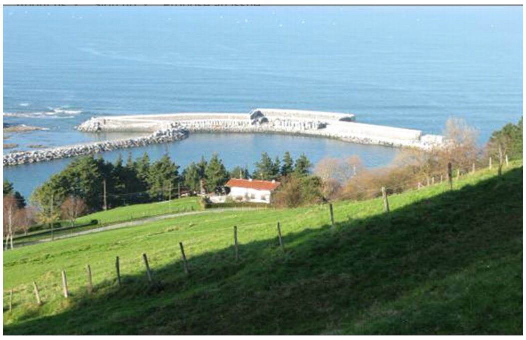
In 1998, the system known as LIMPET (Land Installed Marine Power Energy Transmitter) was installed on the Isle of Islay off the west coast of Scotland **(Figure 4)** by Queen's University Belfast in partnership with Wavegen Ireland Ltd . The plant has been supplying energy to the electrical grid in the United Kingdom. The device comprises three water columns that give a totale water surface area of 169m². The upper part of the tubes is inter-connected and power conversion is via a single turbine generator unit connected to the central column. The PTO system comprises a single 2.6m diameter counter-rotating Wells turbine in which each plane of blades is directly mounted on the shaft of a modified wound rotor induction generator rated at 250kW, giving an installed capacity of 500kW.

Figure 4 : Islay LIMPET (back side) [4]

Figure 5 : Islay LIMPET (front side) [5]

3.1.3.2 Mutriku breakwater - Spain

In spring 2011, the energy authority Ente Vasco Energia (EVE) developed an OWC breakwater using Voith Hydro Wavegen PTO technology at Mutriku in the País Vasco of northern Spain **(Figure 6)**. The design of the Mutriku plant **(Figure 7)** includes a trapezium shaped hollow structure containing 16 ait chambers with 16 wells turbines.Each turbine is 2.83m high, 1.25m wide and weighs 1,200kg. The turbines do not have a gearbox, hydraulics or pitching blades.The turbines are connected to a turbo generator with a capacity of 18.5kW (296kW by the whole plant which is enough to power 250 households).The turbo generator features a butterfly valve at the bottom to isolate it if necessary. This project helps reduce 600t of carbon emissions annually.



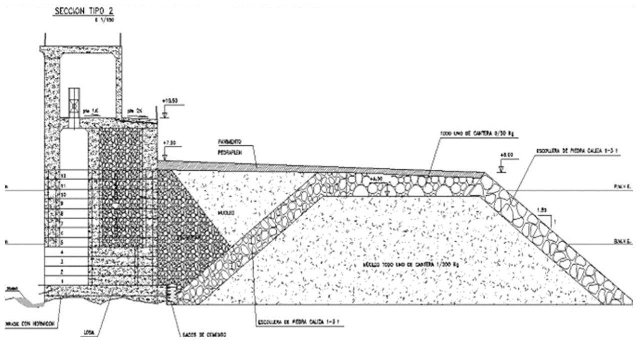


Figure 6 : Mutriku breakwater [6]

Figure 7 : Section through Mutriku breakwater [7]

3.1.3.3 PICO - Azores

PICO is the first onshore experimental structure with a nominal power of 400 kW to use the concept of the OWC. It was commissioned in 1999 as a European demonstration pilot project and is located on Pico Island in the Azores, where the primary resource is evaluated at 13.4 kW/m **(Figure 8).** The power generation unit is made up of a single Wells turbine with 8 blades with a horizontal axis that is 2.3 m diameter, which is directly coupled to a dual-fed wound-rotor induction 400 kW generator operating under 400 V between 750 and 1,500 rpm maximum.

Figure 8 : Front and back views of the PICO [8]

3.1.3.4 Ocean Energy 12 - Ireland

At Spiddal in Galway in Ireland, Ocean Energy has developed the backward bent duct buoy concept (**Figure 9**). The hull has over 20 000 h of live sea trials at the quarter scale. There it was subjected to a wide range of wave conditions, including a severe storm when wind speeds reached 25–30 ms−1 and a wave height of 8.2 m was recorded.

Figure 9 : Ocean Energy buoy with Wells turbine [9]

3.1.3.5 MK3 - Kembla Harbor

An alternative design of floating OWC has been developed by Oceanlinx. Their most recent OWC deployment involved its MK3 floating device. The unit **(Figure 10)** is a one-third scale demonstration version of the 2.5 MW full-scale device. It was installed offshore from the eastern breakwater of Port Kembla Harbor from February to May 2010.

Figure 10 : Mk3 Oceanlinx wave energy generator [10]

3.1.3.6 HACE - France

In 2018, the start-up HACE installed a prototype wave machine at the foot of the bridge on Île de Ré (Nouvelle-Aquitaine). It has developed a technology that produces green hydrogen by converting swell into electricity. Its main characteristic is to produce this energy thanks to small waves of low amplitude. Composed of a series of caissons assembled together, the system can be modulated in order to reach the desired power, i.e. between 10 and 200 kW. It is one of the lowest carbon producers in the world with 0.5g CO2 equivalent/kWh.

Figure 11 : HACE multi chambre offshore system [11]

3.2 Overtopping

3.2.1 Introduction

Wave power devices extract energy directly from the surface motion of ocean waves or from pressure fluctuations below the surface. Captures sea water of incident waves in a reservoir above the sea level, then releases the water back to sea through a turbine. Use low-head hydraulic turbines as power take-off system (PTO) systems. Use the potential energy of water that spills into a closed reservoir to subsequently drive a hydraulic turbine. Overall, there are floating structures with bottom-fixed water reservoirs.

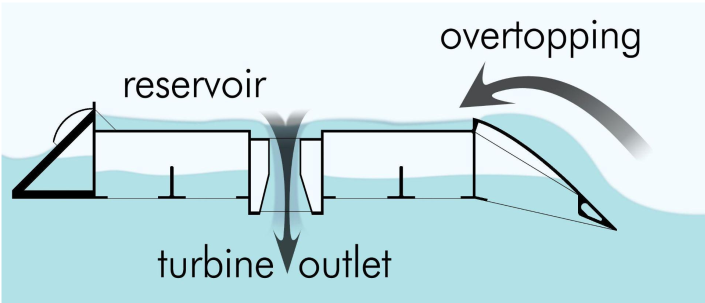


Figure 12 : schema of the function of Wave Dragon [12]

3.2.2 Advantages / Disadvantages

3.2.2.1 Advantages

We can notice some advantages from this device :
- It is not expensive to operate and maintain when the device is shoreline or near-shore.
- No waste is generated during energy capturing or generation.
- It produces a significant amount of energy

3.2.2.2 Disadvantages

Unfortunately, this device has drawbacks. This explains why it had a hard time developing and why there are not many of them in the world:

- The initial installation, research and development costs as well as the manufacturing costs are also high due to the novelty. Indeed, the technology is perceived as high risk due to uncertainties that arise from a lack of familiarity and operational experience.
- Needs a suitable location, where waves are consistently strong. So it’s useful to study wave potentiel all over the world to have the best output.
- Disturb human life. In fact, degradation of scenic ocean front views. Setups can be noisy (binding for nearshore devices).

- Moreover, it's possible threat to navigation from collisions due to the low profile of the wave energy devices above the water, making them undetectable either by direct sighting or by radar. May interfere with anchorage lines with commercial and sport-fishing.
- These new technologies will lead to territorial conflicts. Indeed, more than two-thirds of the oceans are not governed by specific nation-governments but are part of the so-called global commons (Ocean Unite, 2019).
- The structures must be able to withstand extreme rough weather such as heavy precipitation, strong winds, heat waves and abrupt temperature changes. Components need to be amply stress-resistant because of the salinity of seawater. They need to withstand corrosion for extended periods of time.
- There is an overhead of maintaining electric transmission lines. The subsea environment complicates grid deployment and connection as well as maintenance efforts.
- Disturb marine life. In the same way, negative impacts could arise in the form of habitat loss, animal-turbine interactions, noise and electromagnetic fields produced by sea cables, which may have effects on aquatic species.
- The energy is highly dependent on the waves. Hence variable energy supply

3.2.3 Examples

3.2.3.1 Tapchan

Tapchan (**figure 13**) was created in Norway in 1985. It was the first overtopping device in the world. It's a fixed shore out of water and we can find it onshore. Indeed, it was built on cliffs above sea level. Its estimated output is 350 kW and it needs a mean wave power of 24 kW/m to produce energy. Its depth is 20m. It's composed of a tapered channel (which explains its name), a reservoir and turbines. Thanks to the narrowing of the channel, the wave width decreases while its amplitude increases. The waves spill over the walls of the channel and into the reservoir, where the stored water is then fed through a turbine. Then the water is released into the sea by creating energy.

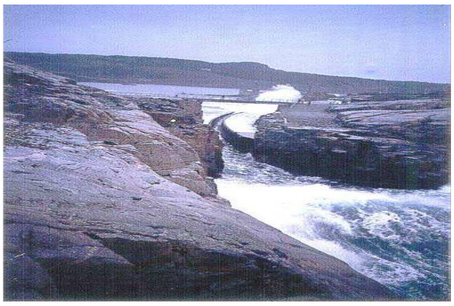


Figure 13 : Tapchan [13]

3.2.3.2 Wave Dragon

Wave Dragon (**figure 12,14)** was created in 2003 in Denmark. It's an offshore plateforme. It's connected to the electrical network on the mainland. It needs a mean wave power of 20 kW/m to function. It's composed of 2 wing reflectors, a ramp, a reservoir and turbines. There are 4 sizes of these devices(tableau). Reflectors concentrate the power of oncoming waves, which pass up a curved ramp and go into the reservoir. Waves climb the ramp or fall into the tank for the water store. Water in the tank flows through the turbines and electricity is generated by water pressure.

The water returns back to sea, like Tapchan. The particular shape of the ramp (wide flat plateau) contributes to waves not breaking. It rolls onto it.

Figure 14 : Wave Dragon [14]

3.2.3.3 SSG (Sea wave slot cone generator)

It was created in Denmark in 2008. It's a project (there is only a prototype). The research has focused mainly on the maximisation of wave power capturing and on the nature and magnitude of wave loadings. The system has undergone six years of R&D, at the Department of Civil Engineering of Aalborg University. It's a fixed shore out of the water such as Tapchan. Its depth is 15 m and its estimated output is 150 kW. It needs a mean wave power of 19 kW/m. The structure consists of a number of reservoirs one on the top of each other above the mean water level. The water of incoming waves is stored temporarily in the reservoir. In each reservoir, expressively designed low head hydro-turbines are converting the potential energy of the stored water into electrical power.

Figure 15 : SSG [15]

3.3. Attenuators

3.3.1 Introduction

In this section you will be introduced to a type of wave energy converter, called an attenuator. An attenuator is a floating device which operates parallel to the wave direction of propagation and rides the waves. These devices capture the wave energy by transforming the wave motion into a mechanical movement as you can see from **figure 16**. Then this mechanical movement is transformed into electricity thanks to a power-take-off (PTO) system. Its name comes from the fact that it attenuates the waves by collecting some of their energy. Such devices are generally situated offshore.

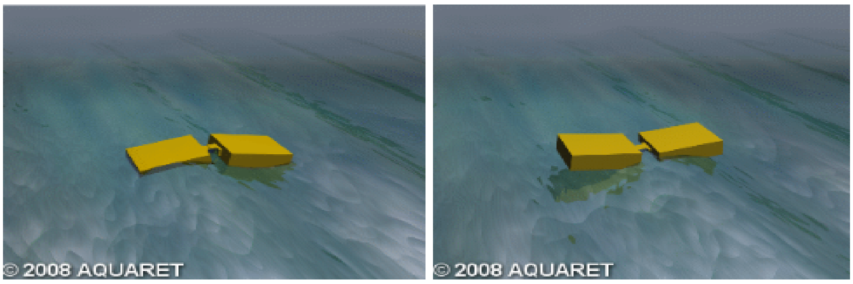


Figure 16 : Principle of operation of an attenuator [16]

3.3.2 Advantages / Disadvantages

3.3.2.1 Advantages

Let's look at the advantages of this type of wave energy converter:
- The biggest advantage of this type of system is that attenuators are located offshore, where the wave energy is generally higher, which allows them to produce more electricity.
- Attenuators are located off the coast and are not easily visible from the coast, so they do not distort the landscape or harm people.
- For most attenuators the installation at sea does not require a foundation as it is simply attached to the seabed by cables.

3.3.2.2 Disadvantages

However, this type of wave energy converter also has some disadvantages, namely
- The further away from the coast they are located, the longer the cable used to bring the electricity to the coast will have to be. The further away they are located from the coast, the longer the cable used to bring the electricity to the coast will have to be, and this can considerably increase the cost of installing such a system.
- Due to the fact that they are offshore, maintenance is not necessarily easy and is more expensive than for on-shore systems.

3.3.3 Examples :

3.3.3.1 The Pelamis

The Pelamis is a project developed by a Scottish company, Pelamis Wave Power, in the early 2000s. This wave energy converter is composed of 4 metal cylinders and 3 power conversion modules articulated together. Its length is 180 m with a diameter of 4 meters. It looks like a sea serpent. The movement of the waves drives the oil pumps situated in its articulations. These pumps send oil under high pressure to the hydraulic engine. Then an alternator is driven and electricity is produced. This electricity is then sent back to the coast thanks to an underwater electric cable. The pelamis is attached to the seabed by cables and is positioned in the wave direction of propagation. It is usually installed a few kilometers offshore, where the depth is about 50 to 60 meters. The maximum power output is 750 Kw for one device, and if we consider an average wave power of 50Kw/m.

Figure 17 : The Pelamis [17]

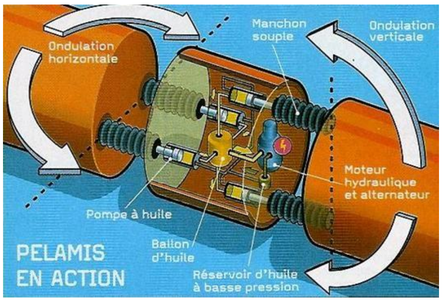


Figure 18 : Pelamis's PTO system [18]

3.3.3.2 The Anaconda

The Anaconda is a wave energy converter system invented in the UK in 2009. It can be described as a giant rubber tube that floats offshore and converts wave energy to electricity. A full-scale device could be up to 150m in length and 6m in diameter. The rubber tube is completely filled with seawater under low pressure. As the sea waves pass along the tube a bulge wave is created and moves with the crest of the wave until the end of the tube. At the end of the tube, water is led thanks to a one way valve system into a high pressure accumulator. Then this HP delivers a constant flow of water which makes the turbine rotate by going into the low pressure accumulator. Therefore electricity is produced continuously thanks to this power take off system and not in periodic cycles. The water is then drawn back into the tube during the reduced pressure phase of the cycle.

The Anaconda is, like the Pelamis, attached to the seabed by cables and is positioned in the direction of wave propagation. It is usually installed a few kilometers offshore, where the depth is about 20m. It should be capable of producing 1Mw of power in an area where the annual average incident wave power amounts to 50Kw/m, enough for a thousand homes.

Figure 19 : The Anaconda wave energy converter [19]

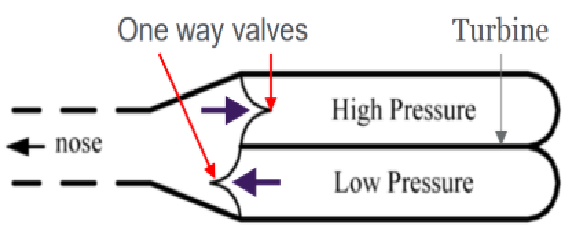


Figure 20 : Anaconda's PTO system [20]

3.3.3.3 The Wave Star

The Wave Star is a wave energy converter project born in Denmark in 2000. A full scale device could be defined as an offshore platform of 240 meters long, to which 40 buoys of 10 meters in diameter are attached. In this device the Wave energy is harvested thanks to the buoys which move up and down. This up and down movement is transferred to hydraulic arms and therefore the oil into the hydraulic arm is compressed and sent under high pressure into the hydraulic system. Then oil is led thanks to a one way valve system into a high pressure accumulator which smooths the flow and delivers a constant flow to the hydraulic engine. Finally electricity is produced. Moreover, the system is set up in such a way that the waves arrive from the side of the buoys, as illustrated on **figure 26**. Therefore the floats are always out of phase with each other. This phase shift ensures that oil is always sent under high pressure to the engine and therefore that electricity is always produced continuously. The Wave Star is designed to operate in 20 m of water depth. The estimated output for a full scale device amounts to 6 Mw in 5,0 meters of Significant Wave Height.

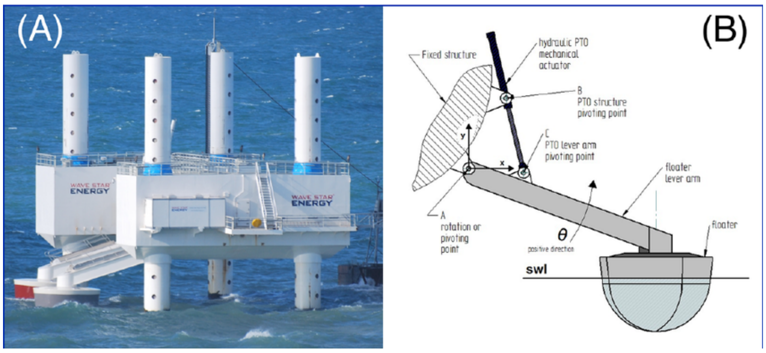


Figure 21 : (A) The Wave star, (B) its PTO system [21]

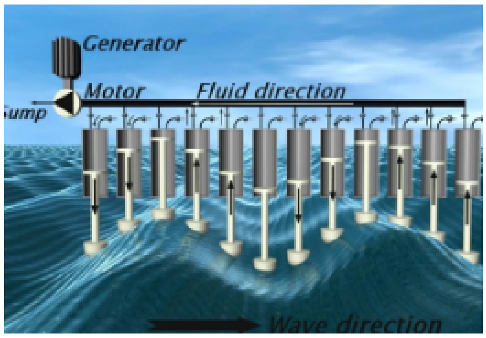


Figure 22 : Installation principle [22]

3.3.3.4 The Salter's Duck

The Salter's duck is a wave energy converter invented by Stephen Salter in Edinburgh in response to the oil shortage in the 1970s. This device is composed of several floating parts called "duck" which are rotating around a central axis. This wave energy converter transforms the wave motion into a mechanical rotation of the duck around a central axis. The rotational motion is then converted into electricity by the power-take-off system (PTO). One way to convert this rotational motion is to use the technology developed by Weptos Company.

The Weptos PTO uses a ratchet mechanism included inside the duck as shown by **figure 24**. Thanks to that, the pivoting motion of the absorber is only transferred to the common axle on the upstroke motion of the duck. Therefore the central axis is rotated in a single direction by the movement of the buoys attached to it. Moreover the rotation of the central axis is at a constant speed because the buoys are out of phase, and finally this central axis drives a generator and electricity is produced. This device should be situated offshore with a sea water depth between 2 and 40 meters. The estimated output for a plant of 20 meters wide amounts to 400 Kw with an average wave power of 50 Kw/m.

Figure 23 : Weptos wave energy converter [23]

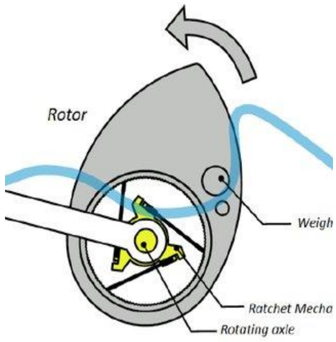


Figure 24 : Weptos's PTO system [24]

3.4 Point absorber

3.4.1 Introduction

Point absorption wave energy conversion technology is one of the more important and most widely researched wave energy utilization technologies. It is partially or fully immersed which extracts energy from the swinging motion of the wave. Generally, it has generators and buoys. According to the installation location, there are coastal, near-shore and offshore. According to the wave energy transfer method, it can be divided into mechanical, hydraulic, direct-drive, piezoelectric and magneto-hydrodynamics. According to the number of oscillating floats in the same device, it can be divided into single point absorption type, combined absorption type and multi-point absorption type.

Figure 25 : Point Absorber [25]

Figure 26 : Point Absorber [26]

3.4.2 Advantages / Disadvantages

3.4.2.1 Advantages

- high conversion efficiency
- low construction difficulty
- low investment cost
- independent of wave direction

3.4.2.2 Disadvantages

- Material problems: Seawater is corrosive, and the waves are extremely destructive. Wave energy devices work where the waves are the largest, and corrosion caused by the harsh marine environment may cause the failure of some links of the device.
- The cost problem: According to relevant experts, the cost of ocean wave energy generation is about 10 times higher than that of conventional thermal power generation.
- Environmental problems: With the increase of wave power generation devices, it will occupy a large area of the sea surface, which is likely to cause harm to marine life and even affect normal commercial shipping.

3.4.3 Examples

We will introduce three devices as representatives, the data of other devices can be found in the appendix 9 with links to view.

3.4.3.1 Searev (France)

There is a closed sealed buoy, and a wheel is suspended in the buoy. The diameter of this wheel is nine meters. It is light on the top and heavy on the bottom, like a pendulum.
For the second generation, the module is in the form of a cylinder 30 m long, 10 m in diameter, and its total mass in operation is 2,200 t. The power installed in a 1/1 scale module is 1 MW. Under the action of the waves, the wheels swing, and the relative motion between the float and the wheels converts the mechanical energy into electrical energy. The current is transmitted to shore via seabed cables

It's a safe and stable device which is easily repaired. Its maintenance will be performed in port after towing the defective machine after decoupling. If one of the modules fails, the others will continue to operate and generate electricity.

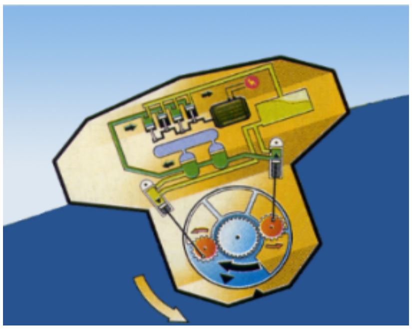


Figure 27 : Searev [27]

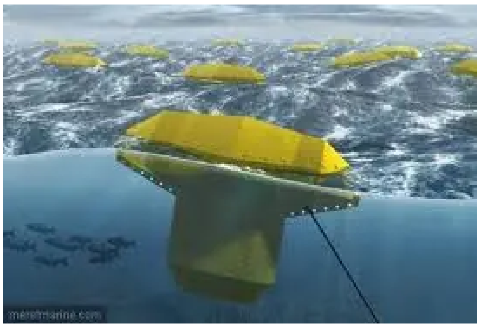


Figure 28 : Searev [28]

3.4.3.2 Wave Bob (USA)

A submerged mass is attached by way of a slender neck to a buoyant inner float structure, a buoyant torus structure, and a Power Take-Off (PTO) with support frame.
Wavebob generates energy primarily from the differential vertical motion (or 'heave') of the torus structure and the inner float. As waves propagate past the device, both structures respond differently. It is this differential movement between the structures which is exploited to generate power.

The Wavebob represents a major breakthrough in wave energy conversion technology given the fact that it can be tuned and controlled . This may be set seasonally or much more frequently as may be justified economically. The instantaneous response of the Wavebob is adjusted rapidly and in real time so that useful power output is maximised.

Figure 29 : Wave Bob [29]

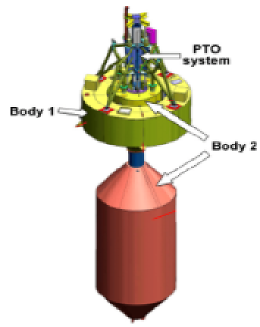


Figure 30 : Wave Bob [30]

3.4.3.3 Archimedes Buoy (Scotland)

The Archimedes Wave Swing is a seabed point-absorbing wave energy converter with a large air-filled cylinder that is submerged beneath the waves. As a wave crest approaches, the water pressure on the top of the cylinder increases and the upper part or 'floater' compresses the air within the cylinder to balance the pressures. The reverse happens as the wave trough passes and the cylinder expands. The relative movement between the floater and the fixed lower part is converted directly to electricity by means of a linear power take-off.

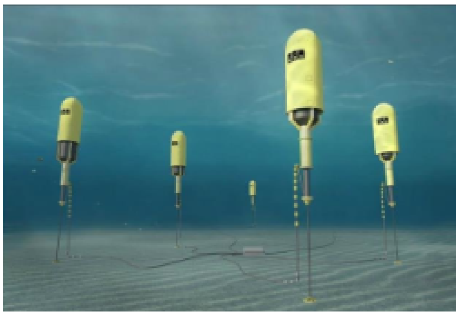


Figure 31 : Archimedes Buoy [31]

3.5 Methodology used for the study of wave potential in the Channel sea

3.5.1 Location

We chose to focus on the installation of a wave energy converter in the British Channel sea. In order to know the optimal location to have the best profit, we had to take into account several characteristics. We needed to find the place where the wave height is the highest, but we also had to take into account the wave direction and the period at different spots. With this data, we could calculate the wave energy using formula (1).

Wave Energy = 0.479 × Wave Period × (Wave Height)² *Formula (1)*

Actually, each person of the group worked on one particular area on the Channel Sea to study the wave's data to determine which location would fit the best to implement the wave energy converter. These are the coordinates for which we studied the wave data (maps in appendix **6.3**) :

- Antoine : 49.257 (N), -4.735 (E) → Offshore area
- Elodie: 50.0.36 (N), -2.2296 (E) → Nearshore area
- Peiwen: 48.944 (N), -3.115 (E) → Offshore area
- Salma : 48.66158 (N), -4.82509 (E) → Nearshore area
- Xinyue: 50.226 (N), -0.181(E) → Offshore area

3.5.2 Methodology

3.5.2.1 ECMWF

After the assignment of the coordinates, we went to the ECMWF site (European Center for Medium-Range Weather Forecasts), which allows us to obtain files containing the data that we will configure. To facilitate our research, the teacher restricted the data to 5 years, that is to say between 2014 and 2018. After selecting the month and the year, we had to find out the time, the step and the parameters we needed. For the time we choose the 4 hours that they proposed (0h00, 6h00, 12h00, 18h00). Then we selected step 0 and finally we took the following parameters : mean wave direction (MWD), mean wave period (MWP) and significant height of combined wind waves and swell (SHW).

Then we have to define the coordinates and the grid. For the grid everybody choose 0.125*0.125 but for the coordinates we put our designated location. For this we had to select the customise option. For instance, Elodie put the following data on the site:

N 48.944 W -3.24 S 48.819 E -3.115

Thanks to all this information the site generates a file with all the data, we just had to download it. We repeated this action for each month of these 5 years. At the end, we obtained 60 files.

3.5.2.2 Matlab

When we had downloaded all the files we used the software Matlab. No one knew how to use it, so the teacher gave us some code files that we needed to run the program. Then we called the function '*getnc*' into the program and we added the file of one of the months that we had downloaded from the site. For example, we call it '*getnc('Janv2014')*'. After we choose the parameter we want the data between MWD, MWP or SHW. We obtained 2 columns of values. Then we used the following function to get 1 column : *Data = ans(:,2,1).* We save all the values into an array. We have this same manipulation for the 3 different data we need (period, direction and height) and for each month of each year that is to say 180 times.

*3.5.*3 Graphs

3.5.3.1 "6 hours" period graph monthly

To compare our results to find which is the best place to implement a wave energy converter we make graphs. In this way, we can easily see the differences between the localisation. We wanted a graph for wave height, wave period and wave energy. And for each parameter we made several graphs (seasonly, 5 years with different hours). First, we needed to sort out the values. The data are arranged in a certain order. In fact, we have (in the same column) :

day 1 0h00/6h00/12h00/18h00 day 2 0h00/6h00/12h00/18h00 …

We needed to separate the data in order to obtain 4 columns for each month which correspond to the different hours. We used this formula to separate the data :

=index($A$1:$A$124 ;LIGNE(C1)*4-3) (it's for the column 0h00)

We did this for each month of the 5 years and for each parameter (3 different). That is to say 180 times.

For instance one of us get that for the wave height:

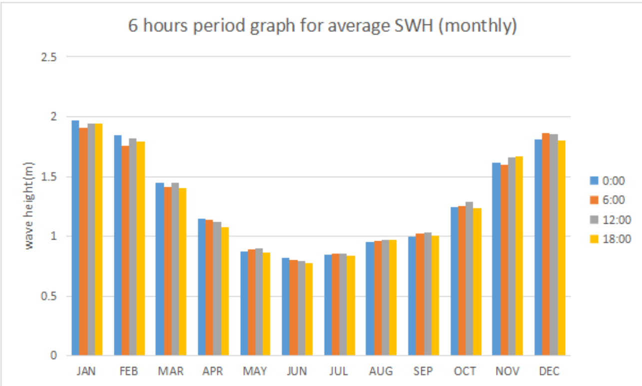


Figure 32 : 6 hours period graph for average SWH (monthly) for Xinyue's area

We can notice on the graph that the wave height is more important during the months of January, February, November and December. We can also see that the height of the wave does not vary much according to the times of the day.

3.5.3.2 Seasonally graph

We also made a graph depending on the season. We have taken 3 months per season for it (for example: winter= January, February,March) we averaged the values and we get the following graph:

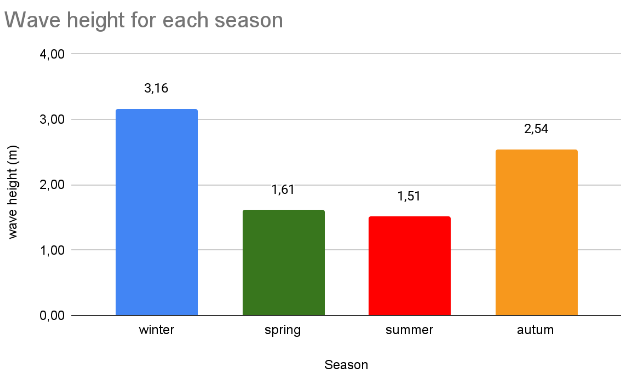


Figure 33 : Seasonally Wave height graph for Antoine's area

If we take a closer look at the seasonal graphs, the lowest wave height data is reached in spring and its value is 0.95m according to Xinyue's graph. On the contrary, the highest wave height data is reached in winter and its value is 3.16m (Antoine's graph) . It is a coherent result because it is in winter that we find the most violent winds and as we have seen previously the energy of the waves is produced thanks to the force of the wind on the surface of the water. Moreover, we can see from our graphs that the season with the highest wave in the Channel Sea remains the winter, data varies between 1.75 m and 3.16 m. Summer and Spring are the seasons with the smaller waves. It varies between 0.95 m and 1.6 m . In general, the data in autumn are also quite important, varying between 1.57 m and 2.54 m. Antoine had the highest values while Xinyue had the lowest values.

3.5.3.3 Yearly graph

Finally, we put in the same graph all of the data (wave height, period and energy) for a period of 5 years:

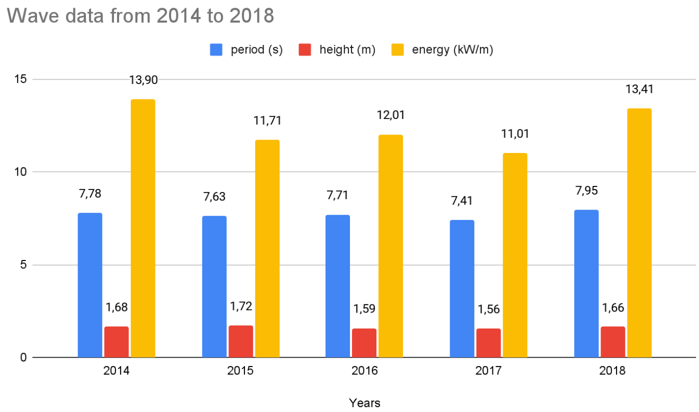


Figure 34 : Yearly wave data for Elodie's area

Thanks to the graph, we can conclude that the wave energy changes every year. For instance, the year to have the best possible energy yield would have been 2014 and the worst would have been 2017. We cannot predict these results as they depend on environmental parameters. But in the Channel sea the wave energy is about 12.5 kW/m. It's an agreement with (**figure 1**). We can see the blue colour between France and the United Kingdom which corresponds to a wave energy of 10 and 20 kW/m.

Concerning the yearly graphs, we can clearly see that 2014 was for most of us the year where the wave energy was the best. Indeed, the wave energy reached from 4.9 kW/m (Xinyue's graph) to 36.07 kW/m (Antoine's graph). Nevertheless, the wave energy tends to decrease the following years and reaches its lowest data in 2017, with a minimum of 4.7 kW/m and a maximum of 24.23 m/s. However, we can notice in 2018 we see a rise of data. As before, Antoine had the best values and Xinyue the worst.

3.5.4 Wave rose

To finish we made a wave rose. This type of graph is very interesting because it allows you to see a lot of information on one graph for each location area. Indeed, it shows the direction of the waves as well as their height. We used an online website (windrose.xyz) [17] to generate the wave rose. First, we have to select a number of directions. Here we took 8 directions (North, East, West, South, NE, NW, SW, SE). Then we entered the minimal and maximal values for the wave height (0 and 4-5m). And we choose a step (1) to classify the data. We get 4 different categories: 0-1, 1-2, 2-3 and 3-4. After, we defined the title of the ax and its unit. Finally, we were able to put our values in an array so the site could generate the wave rose.

To get the values, we had to sort the wave heights according to the directions of their origin. To do this we used a spreadsheet. Indeed, we put the values of wave height and direction and we use this formula :

=SI(ET(ET('wave height'!A1 < 4, 'wave height'!A1 >= 3),ET('wave direction'!A1 < 67.5, 'wave direction'!A1 >= 22.5)), 1, 0)

This gives us the number of hours where waves are between 3-4 m in the direction NE. This formula allows 0 if these 2 conditions are not respected or 1 if the data for the wave height is between 3 and 4 meters AND the wave direction is between 22.5 and 67.5°. Then we just calculate how many 1 do we get and we multiply by 6 because one value corresponds to 6 hours. We repeated this process for each direction (8) and for each category of wave height (4).We changed the values. We did it 33 times, because for the east we had to split in 2 directions. The computer did understand if we told him 337.5<x<22.5 (x represents the wave direction). So we decomposed it like that: 0<x<22.5 and 337.5<x<360. We sort out the values depending on the season. For instance, Elodie get this graph during the winter season:

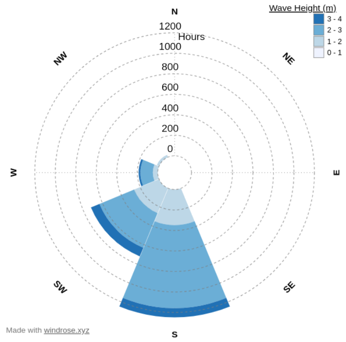


Figure 35 : Winter Wave rose for Elodie's area

The wave rose seems to be coherent because the wind came from the South, it's normal to find a concentration of the highest waves in this direction. Moreover, as we are in winter we find the biggest waves.

3.5.5 Analysis of the extracted data

Globally, for all the areas studied, we notice that the wave energy varies very strongly according to the season. Indeed, according to our data, the wave energy is between 5 and 6 times lower in summer than in winter, due to the different weather conditions. The more there is wind, the more the waves are higher, the speed and then the energy that depends on those two parameters. This is an important thing to take into account in the management of energy distribution on a national scale for example. As far as the direction of the waves is concerned, we can see that globally the waves always come from the south, and that for every area, almost independently of the time of year. This should be taken into account if one wishes to install attenuators, which must be installed in the direction of the wave propagation, so therefore in the channel sea attenuators should be installed following the south-north direction.

3.5.5.1 Antoine : 49.257 (N), -4.735 (E)

If we take a closer look at my geographical area, the seasonal graph shows that the wave energy, in kW/m, varies from an average of almost 60kW/m in winter to only 10 kW/m in summer. Indeed the climatic conditions being milder in summer, the waves are 2 times smaller, 1.51 meters in summer against 3.16m in winter, and the resulting energy is therefore lower.

Moreover, the annual average is usually around 30kW/m, which is a relatively good average. The year 2014 is by far the best with an average of 36kW/m, while 2017 is the lowest with 24kW/m. It is clear that this can vary greatly from year to year.

As for the other areas, my wave rose data shows that the waves come from the south. However they are higher because they can reach almost 6 meters in winter, which gives them more energy according to formula (1).

3.5.5.2 Elodie: 50.0.36 (N), -2.2296 (E)

If we take a global look at the graphs concerning my area, we can notice that 2014 was the year with the best wave data. Indeed, the wave energy reaches the value of 13.9 kW/m whereas in 2017 the value was 11.01 kW/m. There is a downward trend until 2017 but 2018 was a very good year. In fact, it almost reaches the same values as 2014.

Moreover, we also see a huge difference between the wave data over the season. In winter and autumn, it is relatively intense. For instance the wave height reaches 2.31m while in summer and spring, it stays under 1.2m.

If we now take a look at the monthly graph, we can notice that the month with the highest data is January, closely followed by February and December. On the contrary, June, July and August are the months with least activity. We can also see that there is not much difference between the different hours of the day. The waves are quite constant all day.

Finally, regarding the wave rose, we can see that waves came from the South and South-West. Whatever the season, the direction stays the same. What will also change are the heights of the waves. In fact, we find the highest waves in winter and autumn and on the contrary the smallest in spring and summer.

3.5.5.3 Peiwen: 48.944 (N), -3.115 (E)

First of all, let's take a look at the development trend of all charts. The data of each graph shows a concave structure, that is to say, any data shows a peak in winter. With the arrival of summer, the data of each graph reaches the lowest value. Then the data rose in the autumn.

From the average wave height graph, we can see that the peak wave height reached 2.3 meters, and the lowest value was 1 meter.

From the average wave energy, we can learn that the peak value can reach 26Kw in Winter and it reached a minimum value of 4Kw in July. It fluctuated greatly.

From the average wave period, we know that the monthly data gap is very small,which means the wave period fluctuated slightly from month to month and had an average value of 7 seconds.

To sum up, the waves in winter are the most turbulent, and it may have a certain impact on nautical transportation. However, based on the study of waves, waves are the most energetic in winter, which is a great opportunity to extract wave energy.

Then we take a look at the wave data graph, the English channel had the most wave energy of nearly 13 Kw in 2014.For its wave height and wave period, they narrowly have the same value, respectively 1.5m and 7s.

From the wave rose graphs, we can see clearly that the wave directions are SW and S who play the dominant role.

3.5.5.4 Salma : 48.66158 (N), -4.82509 (E)

In this area, the seasonal graph shows that the wave energy varies between 61 kW/m in winter and 10 kW/m in summer. This huge difference is due to climate reasons, as in winter the waves are higher (up to 3m) with a high speed (up to 9,88 m/s) . On the contrary, during the summer, waves are only 1m high and move at 7 m/s.

The annual average is usually around 21kW/m with 2m height and 8.6 m/s. We can see that during the cold months is higher than the average (the highest is in february with 73kW/m, 3,4m and 10m/s) and the warms ones is way too much lower than the average (the lowest is in july with 7kW/m, 1m and 7m/s).

From 2014 to 2018, we didn't see a dramatic increase or decrease of those values. The height and period were around 2m and 8m/s. But, the energy during 2018 was a little higher than the other years.

Finally, regarding the wave-rose , we can notice that the direction doesn't change no matter what season we are in, the waves come from the south. However what changes is the height of the waves, between 0 and 3m during spring and summer, and 0 and 5 m for winter and autumn.

3.5.5.5 Xinyue: 50.226 (N), -0.181(E)

In this area, the average wave energy is 5.064930086 kW/m. If we look at the graph of the wave data, we can see that the five-year data trend is flat, with the highest wave energy in 2015 and 5.86 kW/m,the lowest wave energy in 2016 was 4.71 kW/m.

If we look at the season graph,we can see the data in autumn and winter are significantly higher than those in spring and summer. For example, the maximum wave energy is 10 in winter,and the minimum wave energy is 5.6 in summer.

Then we look at the monthly graph, we can see that the data of January, February, December is the largest, and the data of May, June and July is the smallest. And there are no big fluctuations in the data at different times of the day.

Finally, in the wave rose graph, the shapes of the four season graphs are very similar, indicating that the waves are higher in the south and southwest.

3.5.5.6 Conclusion regarding the data extracted

From this data, we can now conclude which location (**appendix 6.3**) would be the most suitable to implement a wave energy converter. Of all the sites studied, Antoine's is the one that provides the most energy. Being located offshore, attenuators or point absorbers could be installed there. If we put attenuators there, they would have to be oriented from south to north, in the direction of wave propagation. However, offshore wec's produce more but are harder to maintain. So if we wanted to use an oscillating water column or an overtopping, we would choose the coastal site with the most energy, that is to say Salma's area.

In any case we have estimated the wave energy for different sites, but it should be remembered that each wave energy converter has its own efficiency, which varies according to the type, but is generally between 15% and 30%.

4. Conclusion

Today more than ever the world undertakes to fight against global warming. In this way, solutions are being sought to produce energy without greenhouse gas emissions. It is in this context that it becomes necessary to make the most of the renewable resources provided by our planet, and wave energy is one of them.

Indeed, the Ocean is a huge resource and the potential for generating electricity from wave energy is very considerable. According to the World Energy Council, 10% of the world's annual electricity demand could be met by wave energy. As a result, this report presented some types of wave energy converter that could be used to collect this energy, and then we studied the wave potential existing in different areas located in the channel sea.

However there are still several challenges in designing the WECs such as increasing their efficiency and their survivability against harsh conditions. As wave energy is one of the cleanest sources among renewables, it seems to be necessary to make more effort on developing this technology. Using new methods such as computational simulation will speed up the design and testing processes. Finally, it should be mentioned that more research has to be conducted and more money has to be invested in order to make ocean wave energy competitive among other renewable technologies.

The numerous data analysis, including comparative graphs and wind roses that we were able to produce throughout this project, allowed us to conclude that the best place to install a wave energy converter is at a location of 49.275(N) -4.735(E) (Antoine's study). Indeed, it's the perfect spot to put an offshore WEC like a point absorber or an attenuator. However, If we want to build an onshore WEC like an overtopping or an oscillating water column, the best position is 48.66158 (N), -4.82509 (E) (Salma's study).

We hope that our research could help scientists in their work. Moreover, the extensive bibliographical research that we carried out prior to this analysis enabled us to learn a great deal about the various types of wave energy converters.

Finally, we would like to stress the fact that, thanks to Mr ALAMIAN, a researcher, we could see a concrete example of a job that we could do in a few years when we will graduate as an engineer. It was a rich learning experience and we felt very lucky to have the opportunity working alongside him.

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6. Appendixes

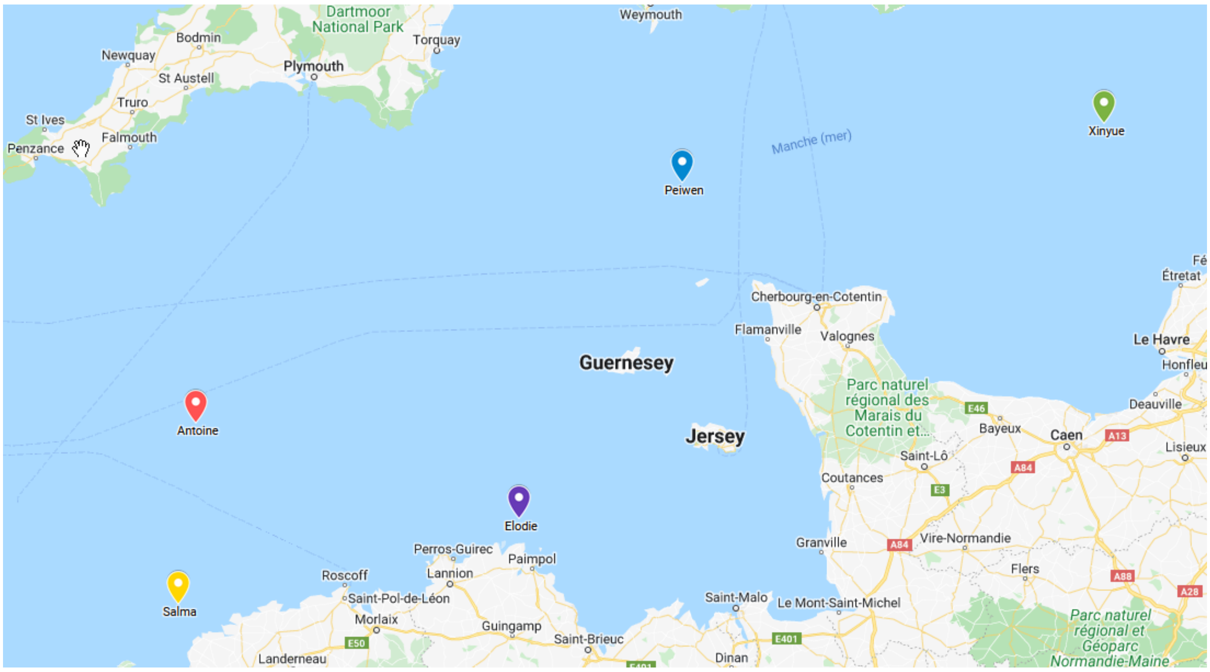
6.1 Different type of Wave Dragon

	1.5MW	4MW	7MW	12MW
weight (t)	237	22 000	33 000	54 000
width and length (m)	58*33	260*150	300*170	390*220
length reflector (m)	28	126	145	190
height (m)	3.6	16	17.5	19
reservoir (m^3)	55	5000	8000	14 000
number of turbines	7	16	16-20	16-24
water deep (m)	6	20	25	35
annual production (GW/year)		12	20	35

6.2 Examples of wave absorbers

Wave absorber	**Type**	**Mean wave power(kW/m)**	**Output power(kW)**
SEAREV	Floating ocean surface	40	500
L10	Floating in the ocean	20	10
OPT power	Fixed in the ocean	50	40-500
AquaBuoy	Fixed Ocean surface	15-50	250
Archimedes Buoy	Fixed seabed	15	250
Uppsala	Fix seabed	20	5
WaveBob	Fixed ocean surface	20-70	500
WaveRoller	Floating seabed	15	300
BioWave	Fixed seabed	50	250-1000
Pendulum	Fixed shore	15	20-300

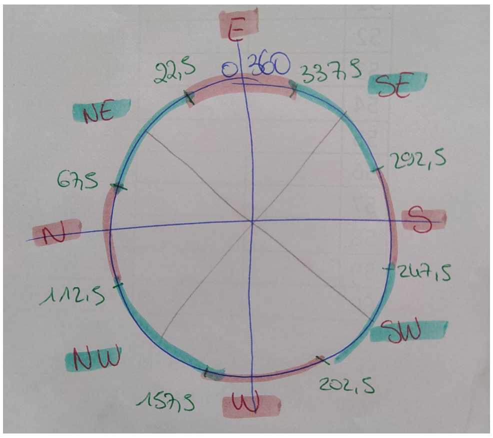
6.3 Location of each area we studied



6.4 Wave rose values

Winter	0-1	1-2	2-3	3-4	Autumn	0-1	1-2	2-3	3-4
E	0	0	0	0	E	0	0	0	0
SE	0	0	0	0	SE	0	24	30	0
S	0	348	810	90	S	0	576	720	6
SW	0	264	366	90	SW	0	474	138	0
W	0	48	102	18	W	0	168	48	0
NW	0	24	0	0	NW	0	18	6	0
N	0	0	0	0	N	0	0	0	0
NE	0	0	0	0	NE	0	0	0	0
Spring	0-1	1-2	2-3	3-4	Summer	0-1	1-2	2-3	3-4
E	0	0	0	0	E	0	0	0	0
SE	54	60	0	0	SE	66	120	0	0
S	192	738	6	0	S	426	942	0	0
SW	222	678	0	0	SW	78	450	6	0
W	54	114	0	0	W	30	90	0	0
NW	0	30	0	0	NW	0	0	0	0
N	0	12	0	0	N	0	0	0	0
NE	0	18	0	0	NE	0	0	0	0

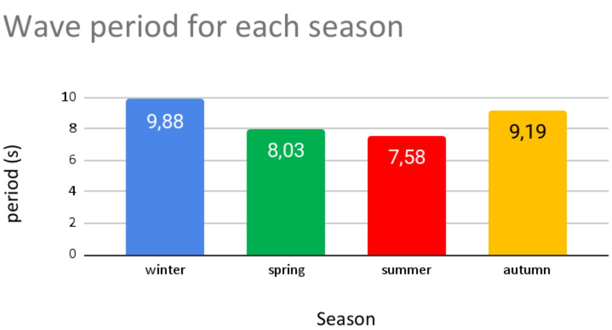
6.5 Compass

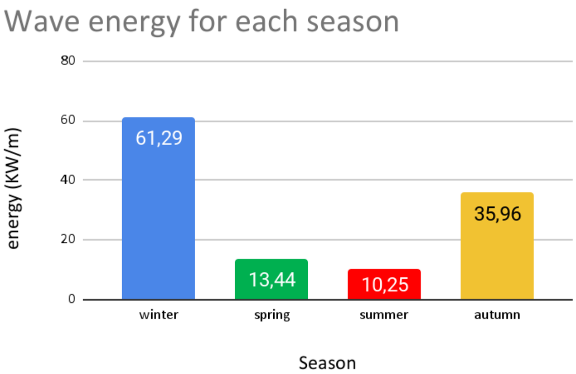


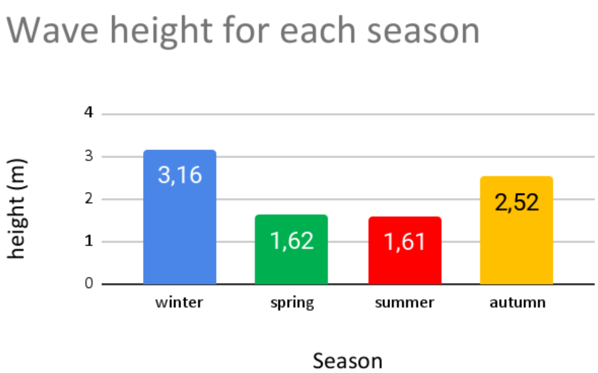
6.6 Graphs reporting the wave data for each areas studied

6.6.1 Seasonal graphs :

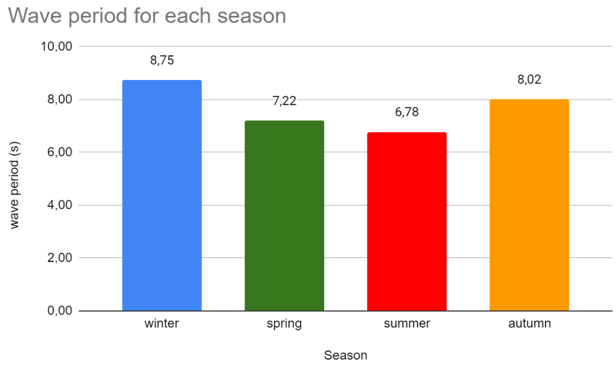
6.6.1.1 Salma's area

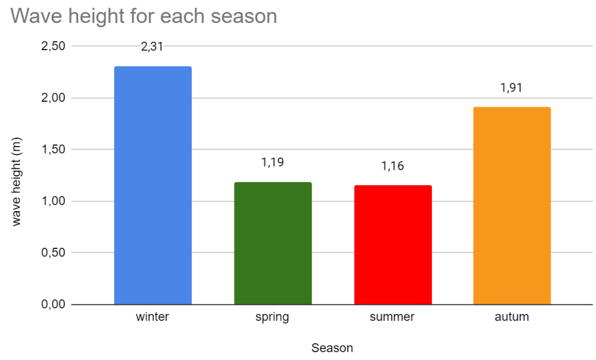


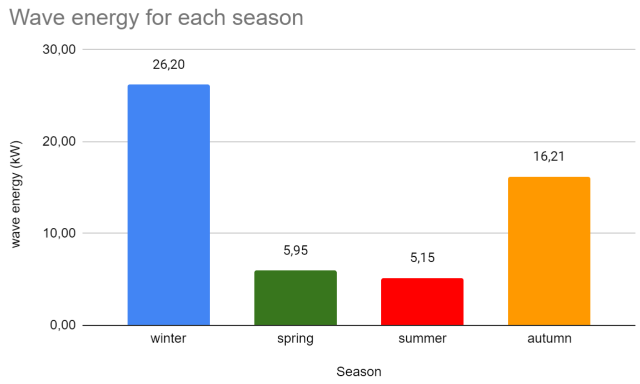




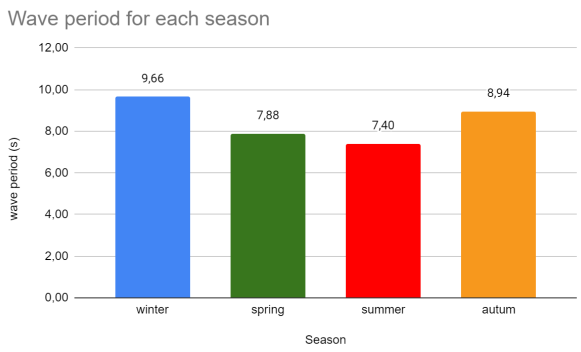
6.6.1.2 Elodie's area

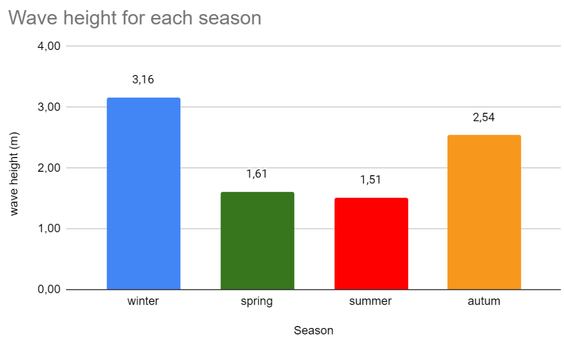


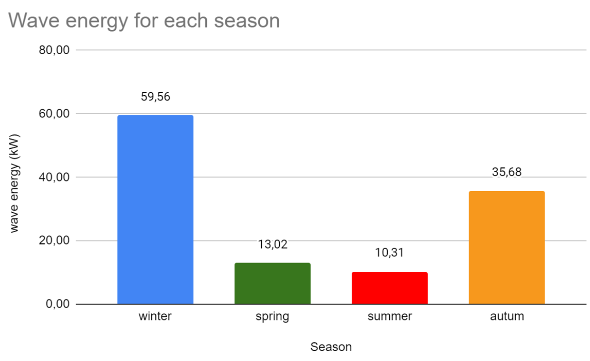




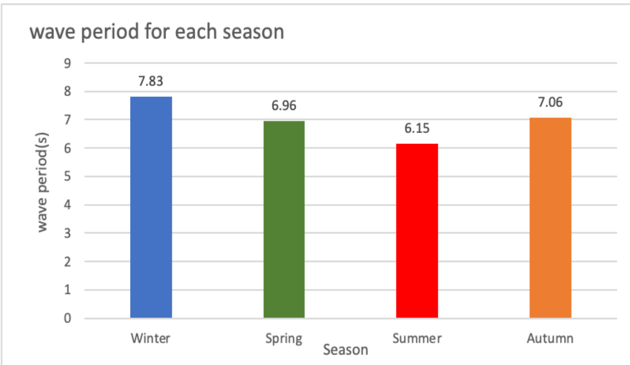
6.6.1.3 Antoine's area

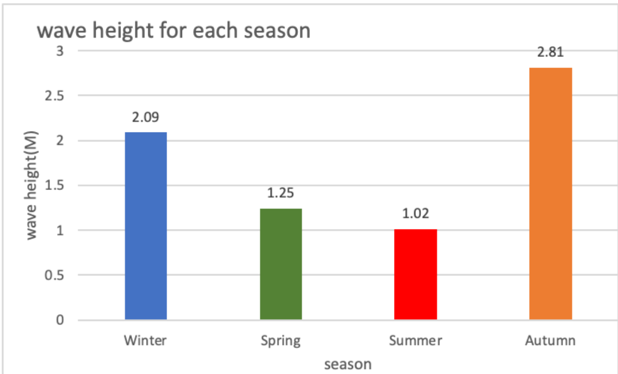


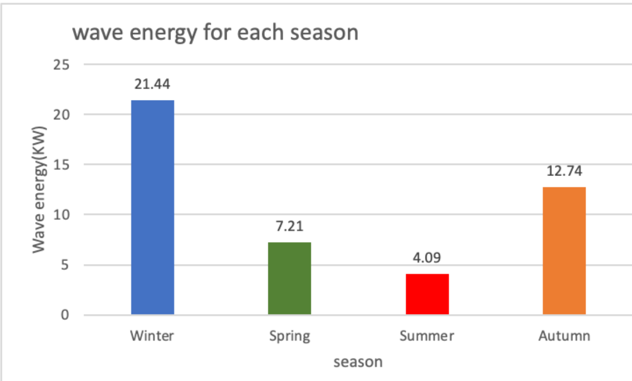




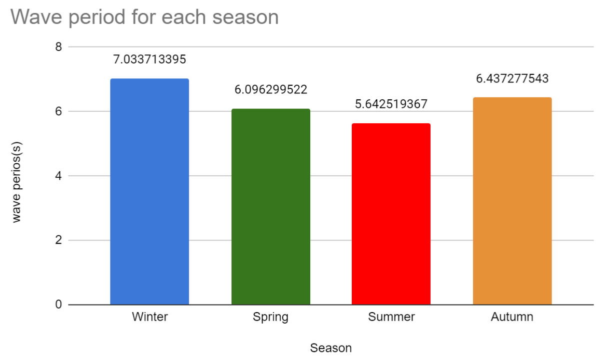
6.6.1.4 Peiwen’s area

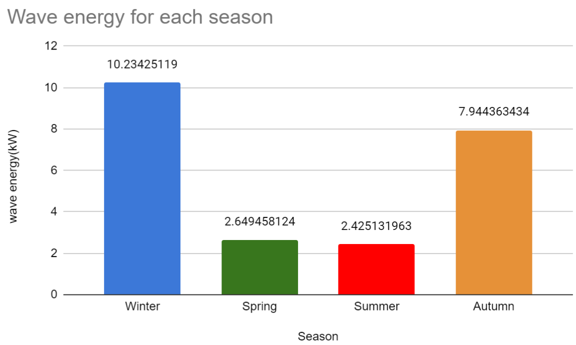






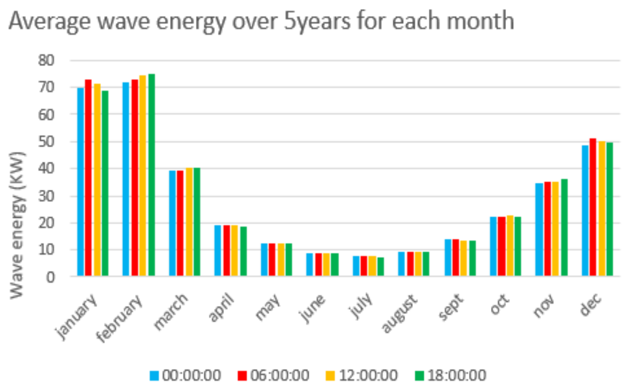
6.6.1.5 Xinyue's area

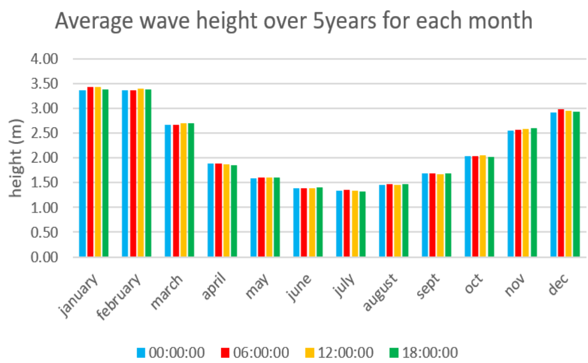


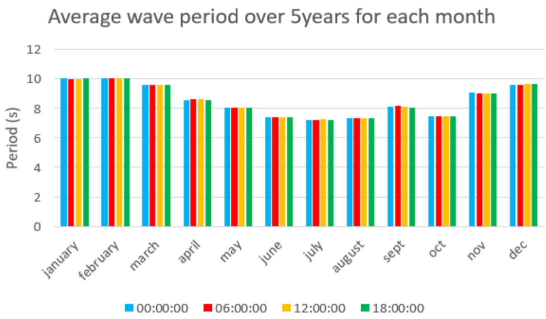


6.6.2 Yearly graphs:

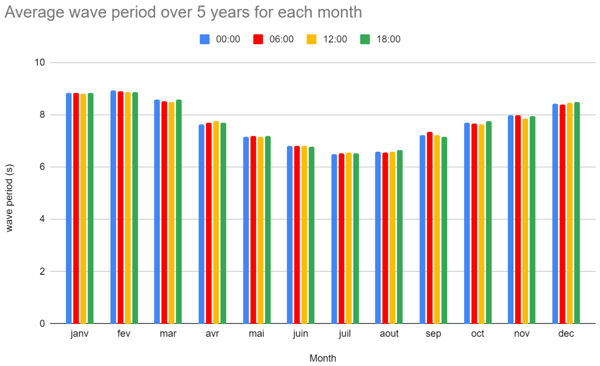
6.6.2.1 Salma's area

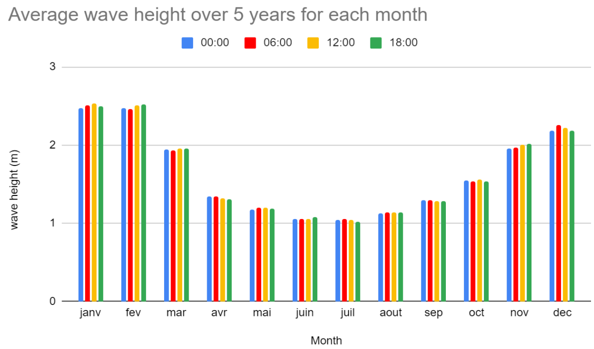


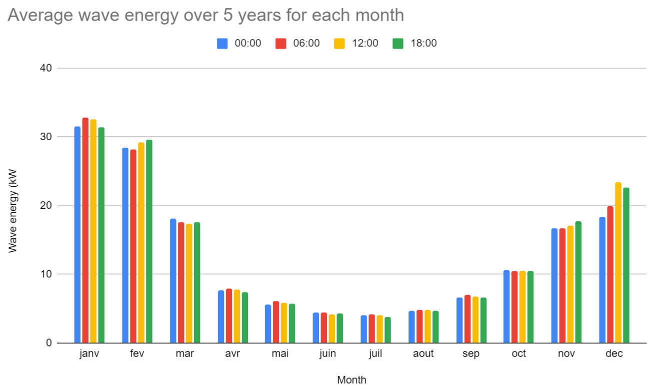




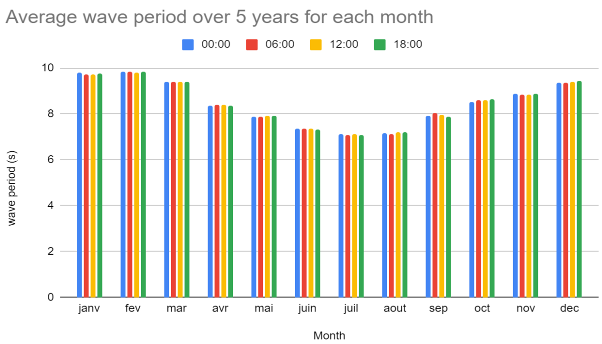
6.6.2.2 Elodie's area

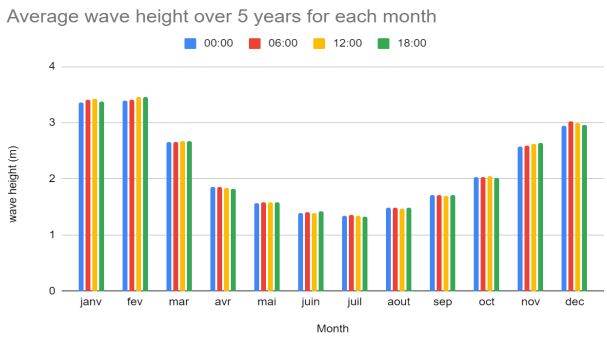


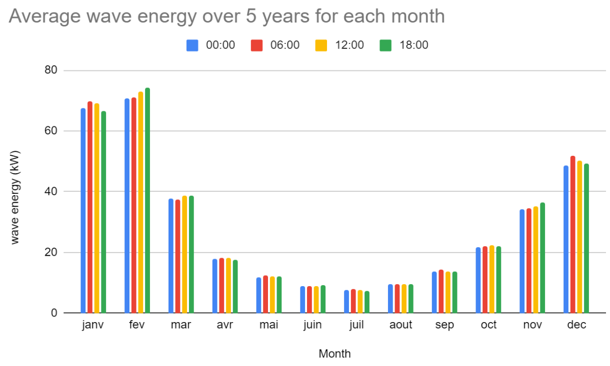




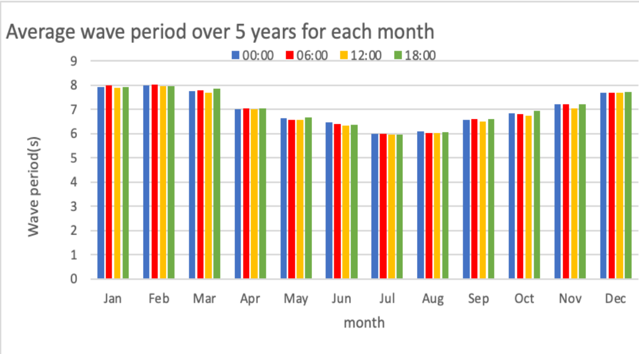
6.6.2.3 Antoine's area

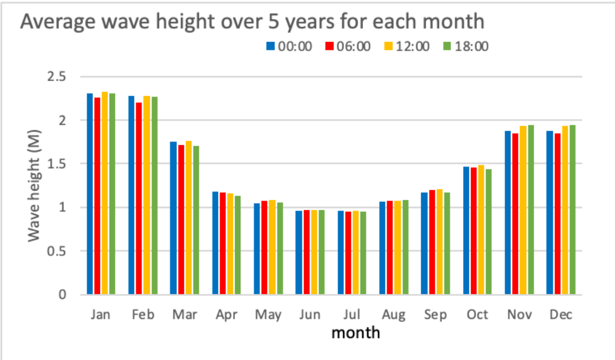


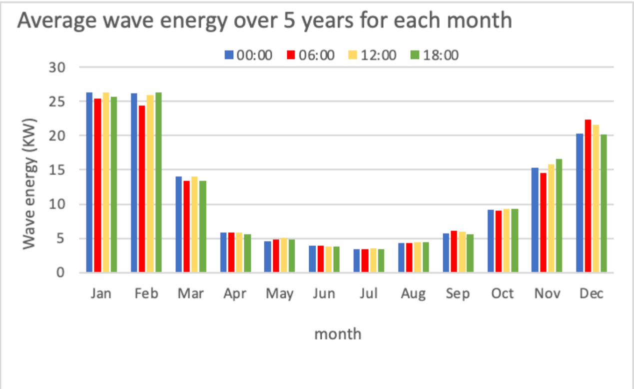




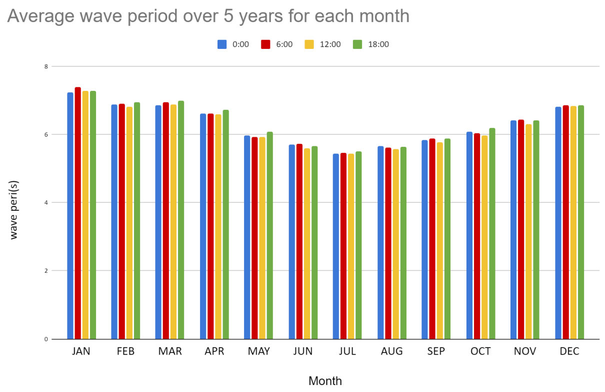
6.6.2.4 Peiwen's area

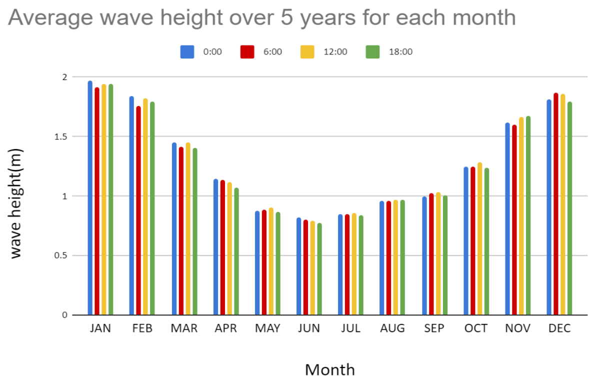


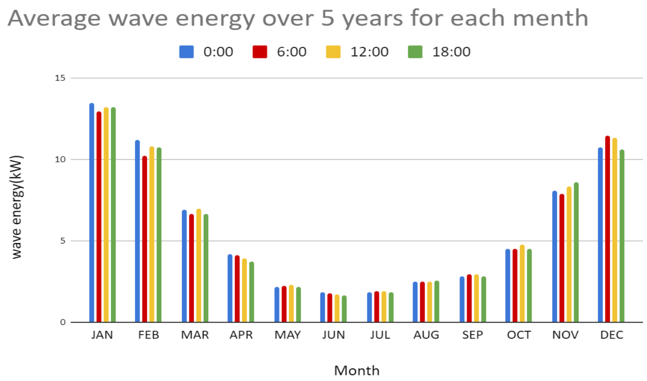




6.6.2.5 Xinyue’s area



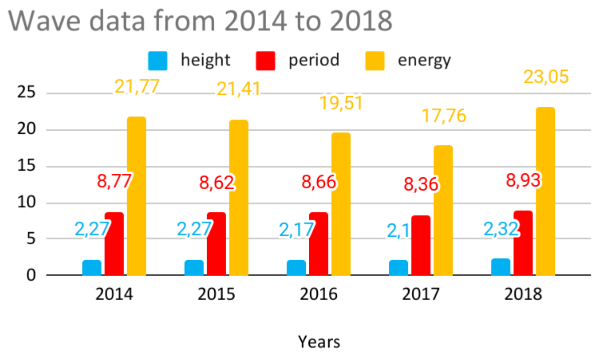


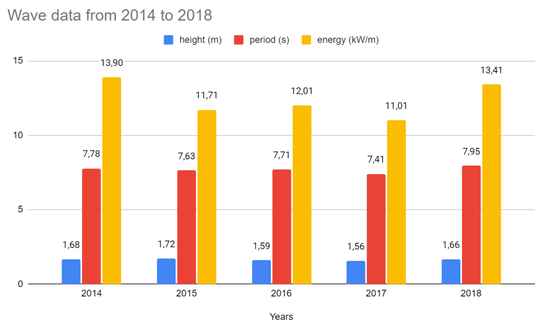


6.6.3 Summary graphs:

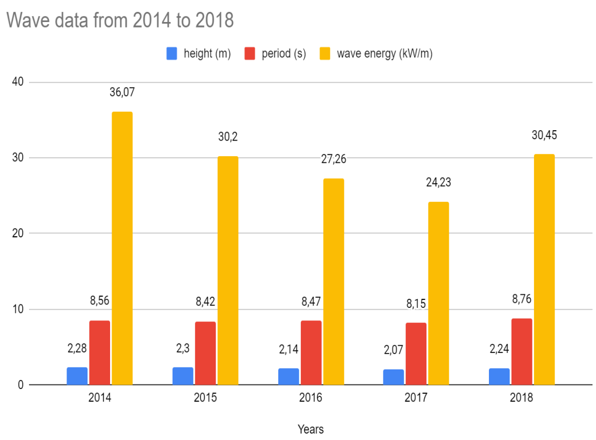
Salma’s area

Elodie’s area

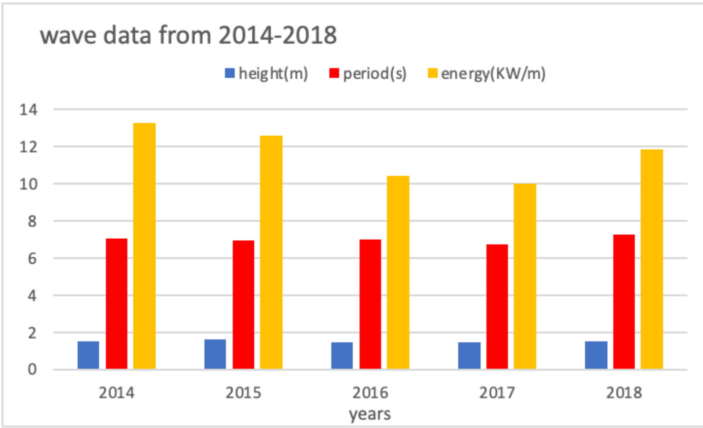




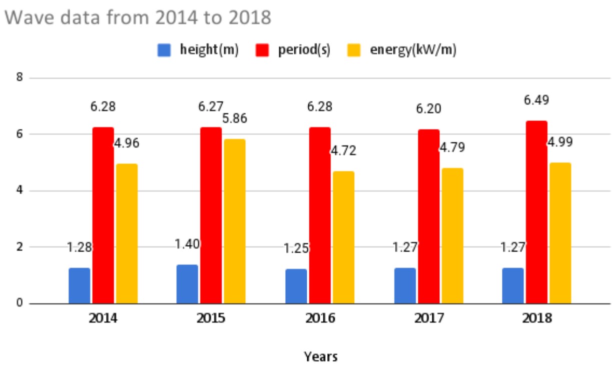
Antoine's area



Peiwen's area

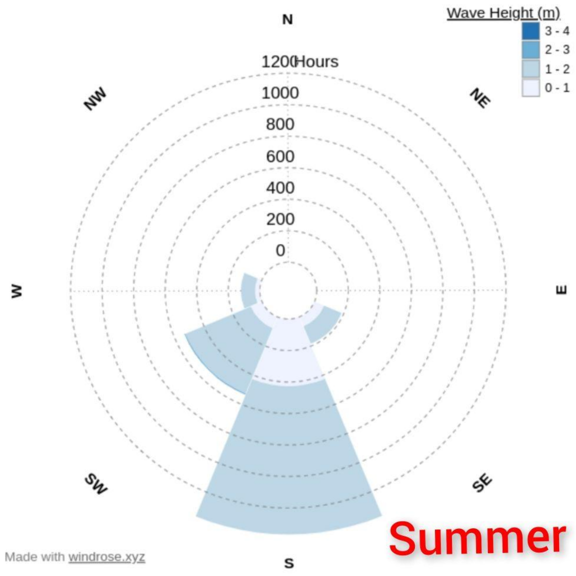


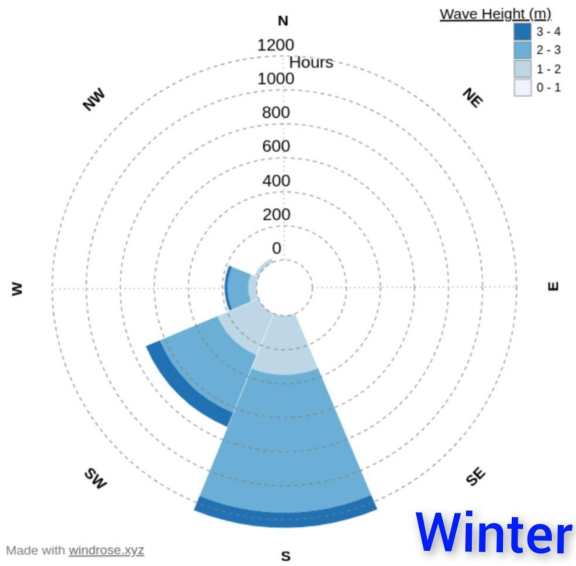
Xinyue's area

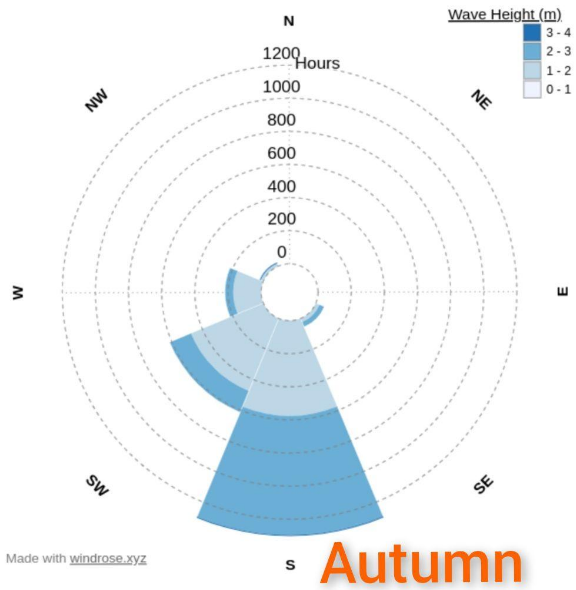


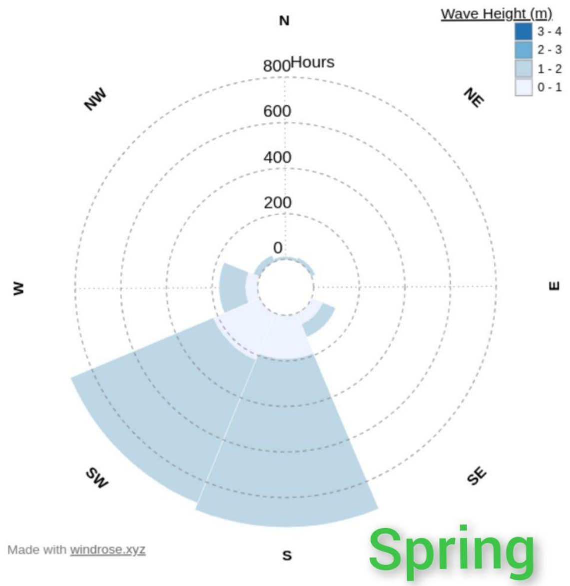
6.6.4 Seasonal wave rose graphs

6.6.4.1 *Elodie's Area*

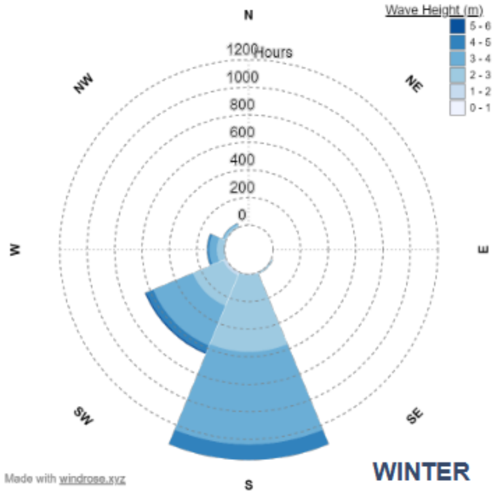


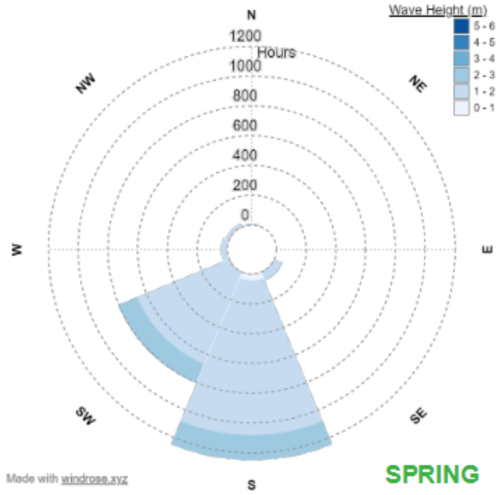


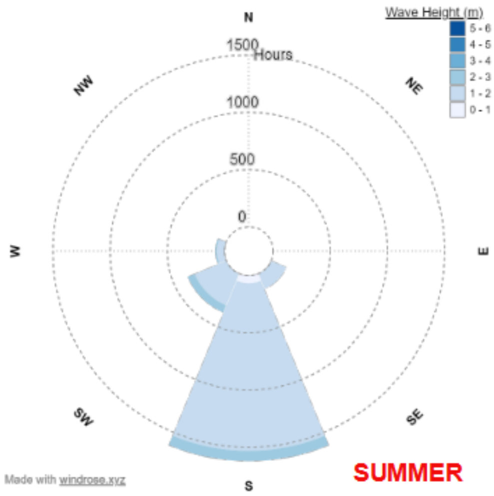


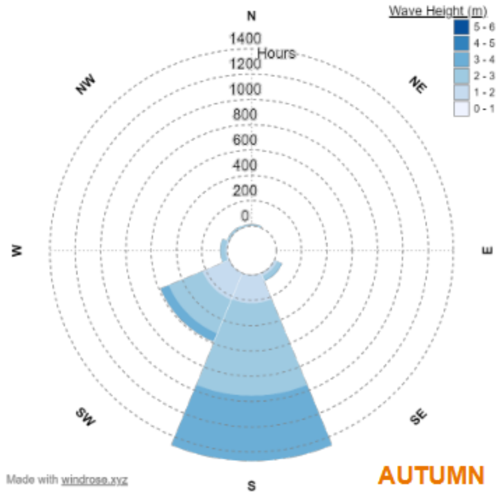


6.6.4.2 *Antoine's Area*

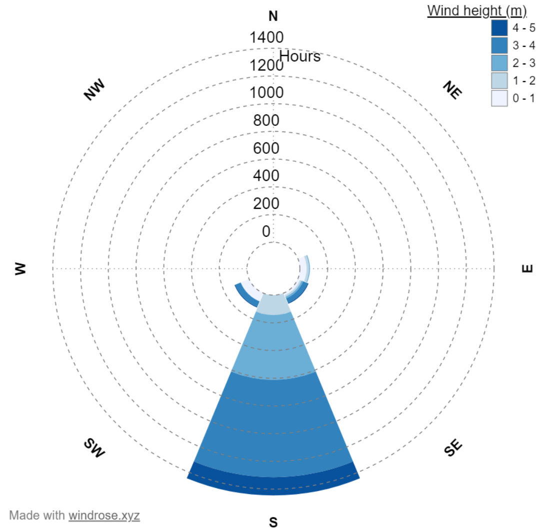




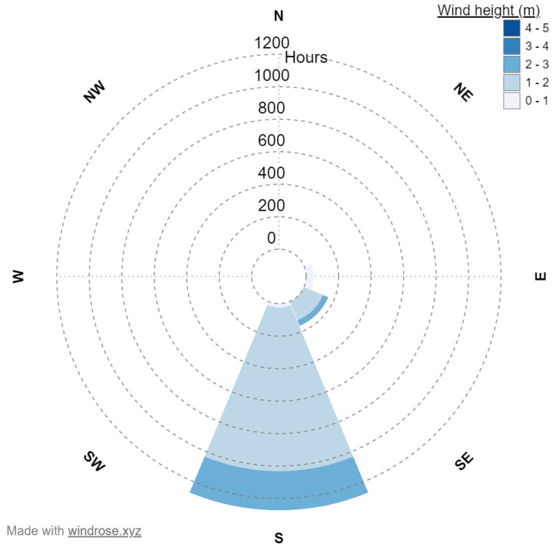




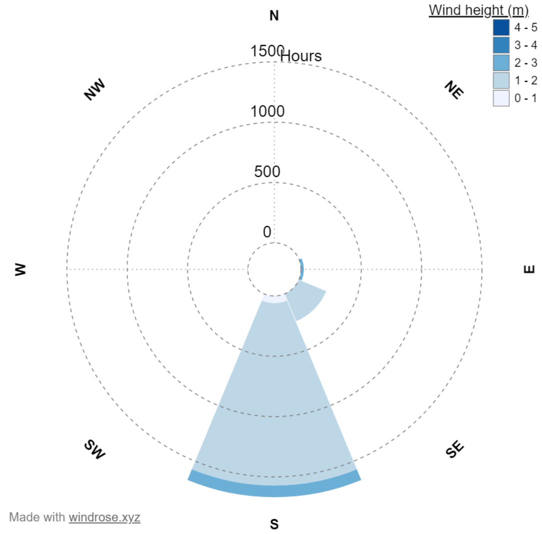
6.6.4.3 Salma's Area



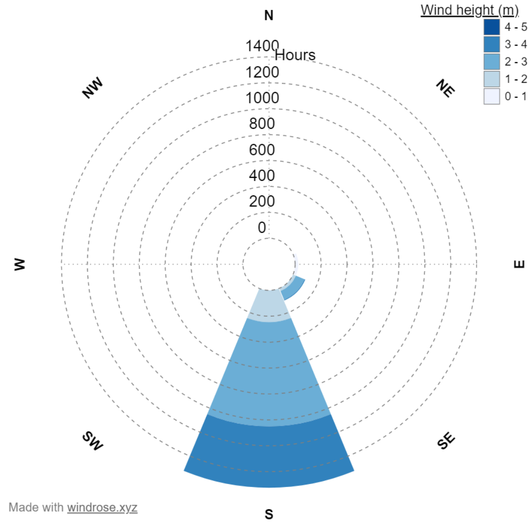
WINTER



SPRING

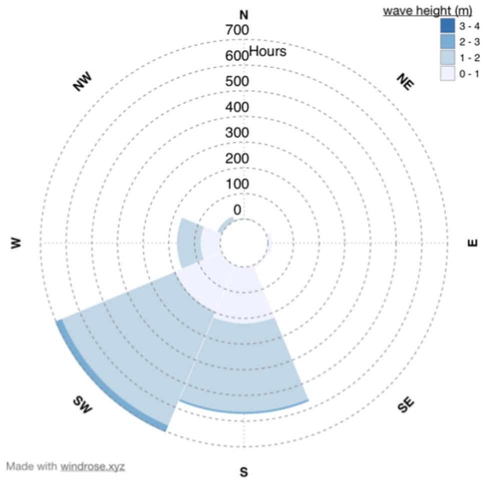


SUMMER

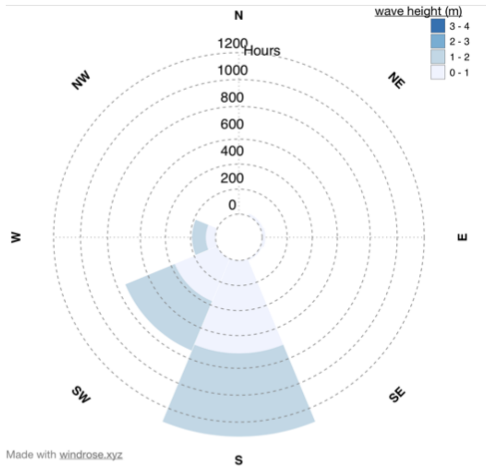


AUTUMN

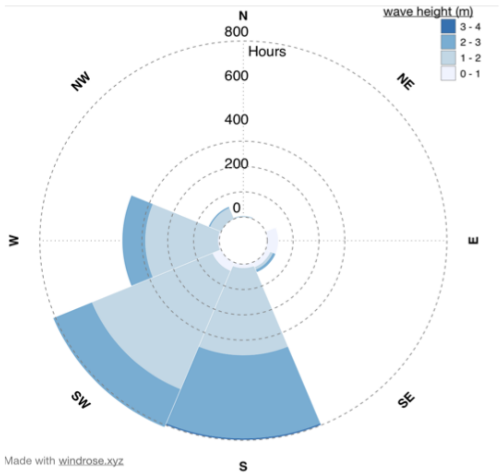
6.6.4.4 *Peiwen's Area*



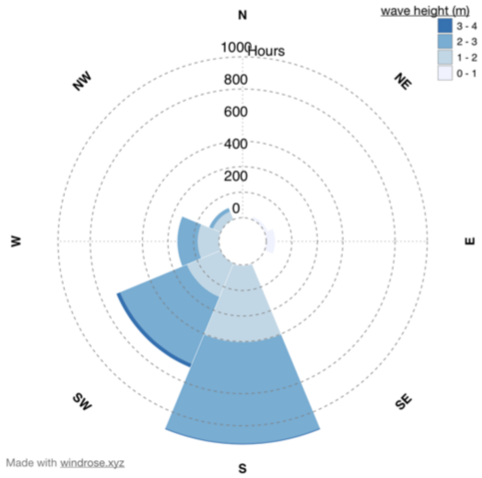
Spring



Summer

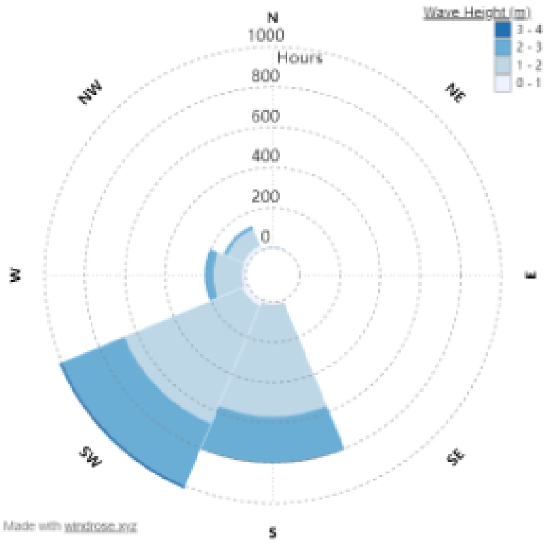


Autumn

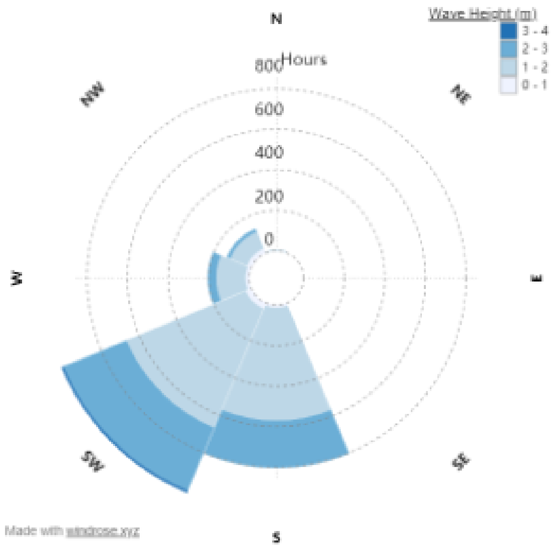


Winter

6.6.4.5 *Xinyue's Area*



WINTER



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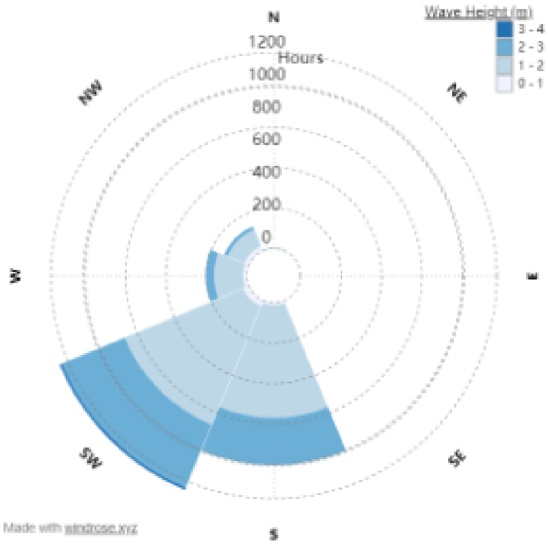
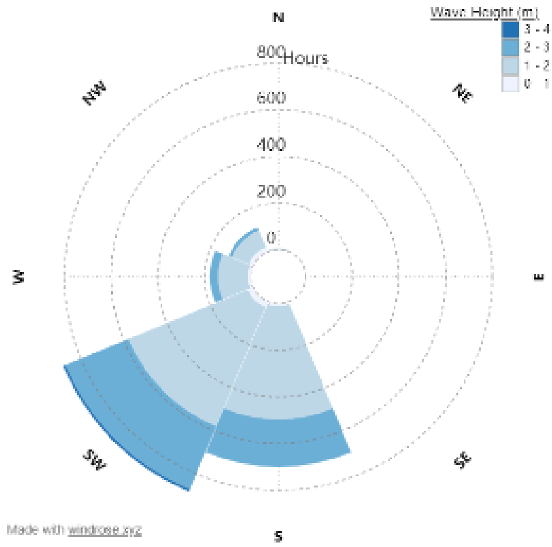


SUMMER



AUTUMN