UNIVERSITA' POLITECNICA DELLE MARCHE

ENVIRONMENTAL ENGINEERING

Hydraulic engineering and renewable energy

WEC PROJECT

Done by:

Passon Andar

Qudratullah Ramzi

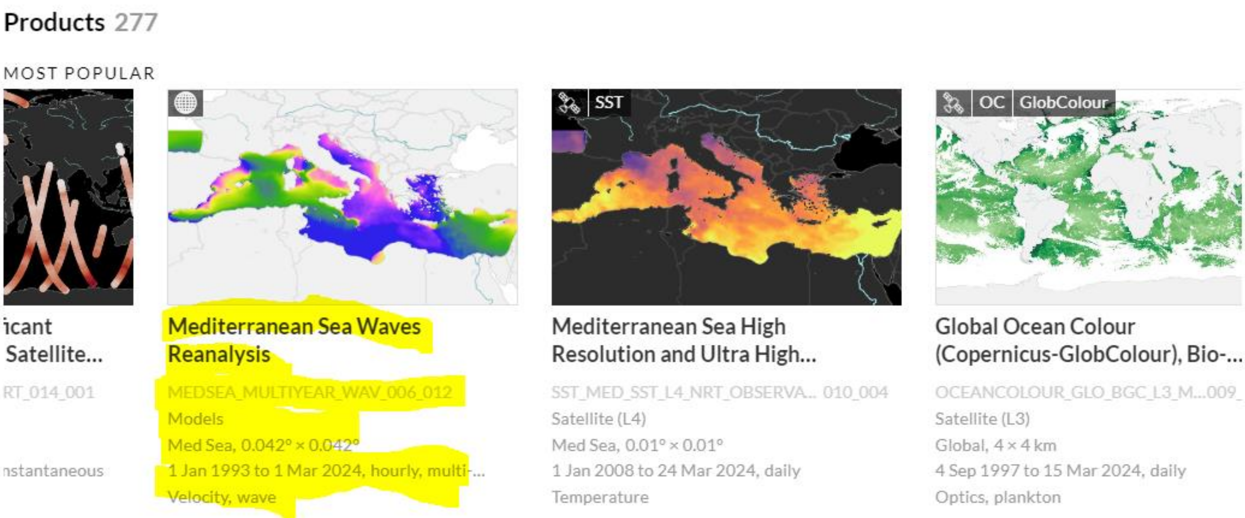
Submitted to:

Prof. Dr. Eng. Matteo Postacchini,

Contents

1. Location selection

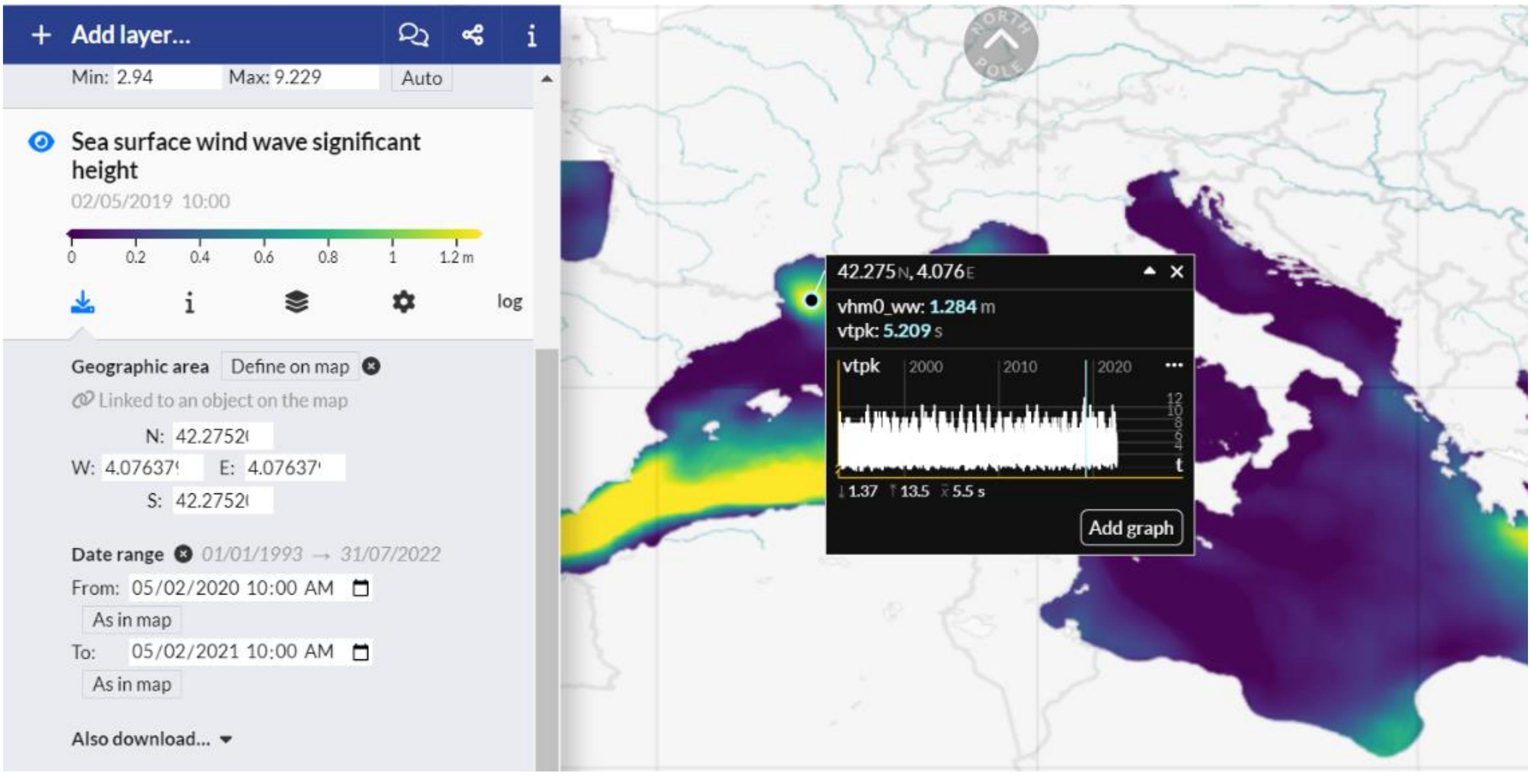
To figure out how much energy offshore wave energy converters (WECs) can generate each year, we picked two spots using the Copernicus platform. Copernicus is a website where you can get free info about Earth stuff like weather, oceans, and more. We're mainly interested in the marine part of Copernicus (CMEMS), which gives trustworthy info about the oceans worldwide.



In this project we selected 2 different location (1 for each student) were selected to compare the results and select whichwill result the best node. They are showed in the following pictures/figures:

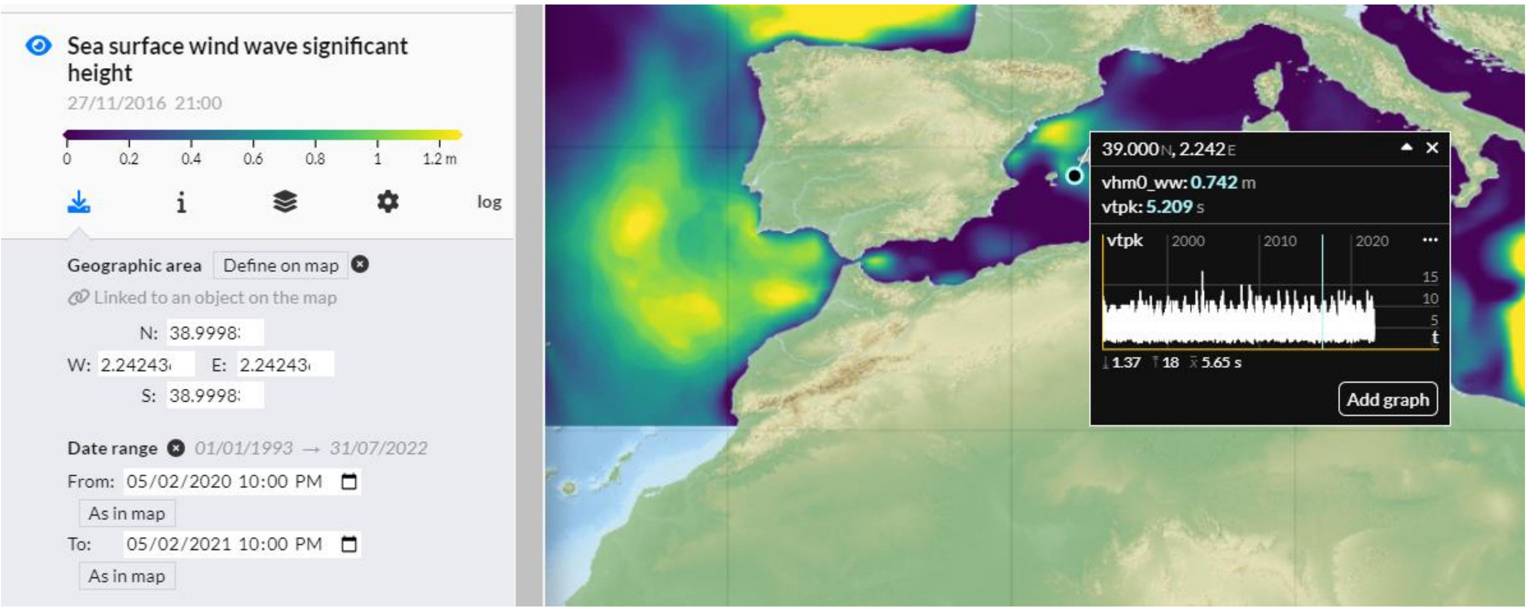
LOCATION 1:

Student: Passon Andar



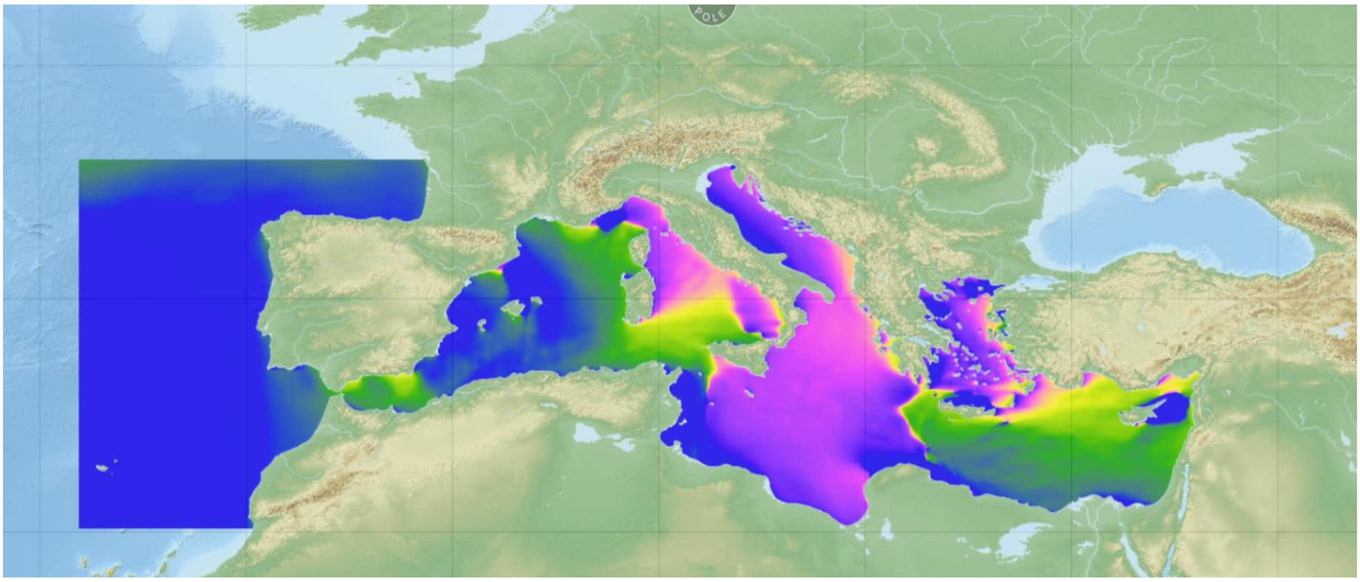
LOCATION 2:

Student: Qudratullah Ramzi



1. DOWNLOAD DATA OF THE SEA-STATE FROM THE COPERNICUS PLATFORM: SIGNIFICANT HEIGHT AND PEAK PERIOD

Available Data were downloaded on the Copernicus Marine Data Store, from the product "**Mediterranean Sea Waves Reanalysis"** considering "Sea surface wave significant height" and the "Sea surface wave period at variance spectral density maximum" of the sea-state in the 2 corresponding nodes in the reference period (1 year): **from Feb 5th 2020 to Feb 5th 2021.**



Dataset

Product identifier	MEDSEA_MULTIYEAR_WAV_006_012
Product name	Mediterranean Sea Waves Reanalysis
Dataset	*Please choose one of the datasets in this product:* med-hcmr-wav-rean-h

Variables* Add all Clear all

- [x] Sea surface wave significant height *VHM0* [m]
- [ ] Sea surface primary swell wave significant height *VHM0_SW1* [m]
- [ ] Sea surface secondary swell wave significant height *VHM0_SW2* [m]
- [ ] Sea surface wind wave significant height *VHM0_WW* [m]
- [ ] Sea surface wave from direction *VMDR* [°]
- [ ] Sea surface primary swell wave from direction *VMDR_SW1* [°]
- [ ] Sea surface secondary swell wave from direction *VMDR_SW2* [°]
- [ ] Sea surface wind wave from direction *VMDR_WW* [°]
- [ ] Sea surface wave from direction at variance spectral density maximum *VPED* [°]
- [ ] Sea surface wave stokes drift x velocity *VSDX* [m/s]
- [ ] Sea surface wave stokes drift y velocity *VSDY* [m/s]
- [ ] Sea surface primary swell wave mean period *VTM01_SW1* [s]
- [ ] Sea surface secondary swell wave mean period *VTM01_SW2* [s]
- [ ] Sea surface wind wave mean period *VTM01_WW* [s]
- [ ] Sea surface wave mean period from variance spectral density second frequency moment *VTM02* [s]
- [ ] Sea surface wave mean period from variance spectral density inverse frequency moment *VTM10* [s]
- [x] Sea surface wave period at variance spectral density maximum *VTPK* [s]

2. BUILD THE SCATTER MATRIX (OCCURRENCE PROBABILITY AS FUNCTION OF Hs AND Tp), USING Hs INTERVALS OF 0.2m AND Tp INTERVALS 0.5s

Inspect the content of the netCDF dataset

The downloaded data were opened in Matlab. The data are in a specific, standard format called **netCDF**, as shown by the extension (.nc) . We needed a bit of post-processing to extract the variables from the file. To investigate the structure of this dataset and check the variables contained in it, the function **ncdisp** was used.

```
           subset:date      = "2024-03-24T13:26:25.624Z"
Dimensions:
           latitude  = 1
           longitude = 1
           time      = 8761
Variables:
    VHM0_WW
           Size:       1x1x8761
           Dimensions: longitude,latitude,time
           Datatype:   single
           Attributes:
                       units         = "m"
                       _FillValue    = NaN
                       standard_name = "sea_surface_wind_wave_significant_height"
                       long_name     = "Spectral significant wind wave height"
    VTPK
           Size:       1x1x8761
           Dimensions: longitude,latitude,time
           Datatype:   single
           Attributes:
                       units         = "s"
                       _FillValue    = NaN
                       standard_name = "sea_surface_wave_period_at_variance_spectral_density_maximum"
                       long_name     = "Wave period at spectral peak / peak period (Tp)"
    latitude
           Size:       1x1
           Dimensions: latitude
           Datatype:   single
           Attributes:
```

As observed, downloading data for a single location from Copernicus platform, we have the dimensions: 1 point in longitude and 1 point in latitude, and 8761 points in time (representing the hours of data for a single node in a particular year)

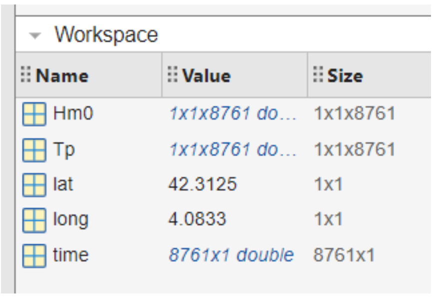
Extract the variables of the netCDF dataset and plot graph of thew significant wave height

We can extract the variables using the **ncread** function.

The variables in the file are as follows:

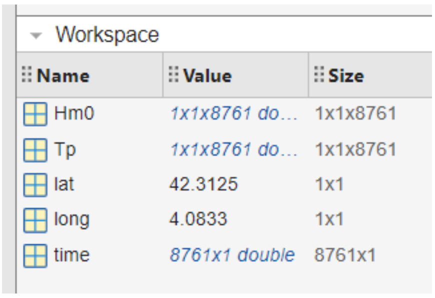
- VTPK: Peak wave period (**Tp**) with dimensions 1x1x8761
- VHM0: Significant wave height (**Hs**) with dimensions 1x1x8761.
- **Longitude** and **Latitude** variables containing the coordinates of the downloaded node (single values, as we downloaded a single node).
- **Time**: time vector indicating the hours each specific data corresponds to. Time is given in seconds, referred to as Posixtime in Matlab.

Since the time variable is expressed in seconds since January 1, 1970, it was converted into dates using the **datetime** function.

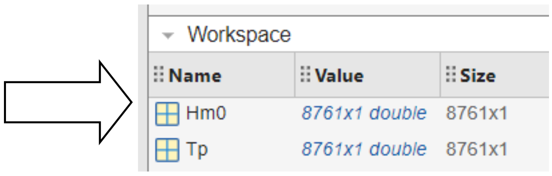


Name	Value	Size
Hm0	1x1x8761 do...	1x1x8761
Tp	1x1x8761 do...	1x1x8761
lat	42.3125	1x1
long	4.0833	1x1
time	8761x1 double	8761x1

Now, it is possible to plot the variables using the plot function. However, before proceeding, it's important to note that the data extracted from the NetCDF file are arrays (3D data), while the plot function handles vectors or matrices. To address this, we converted Hm0 and Tp its structure from 1x1x8761 into a vector 8761x1 using the squeeze function.

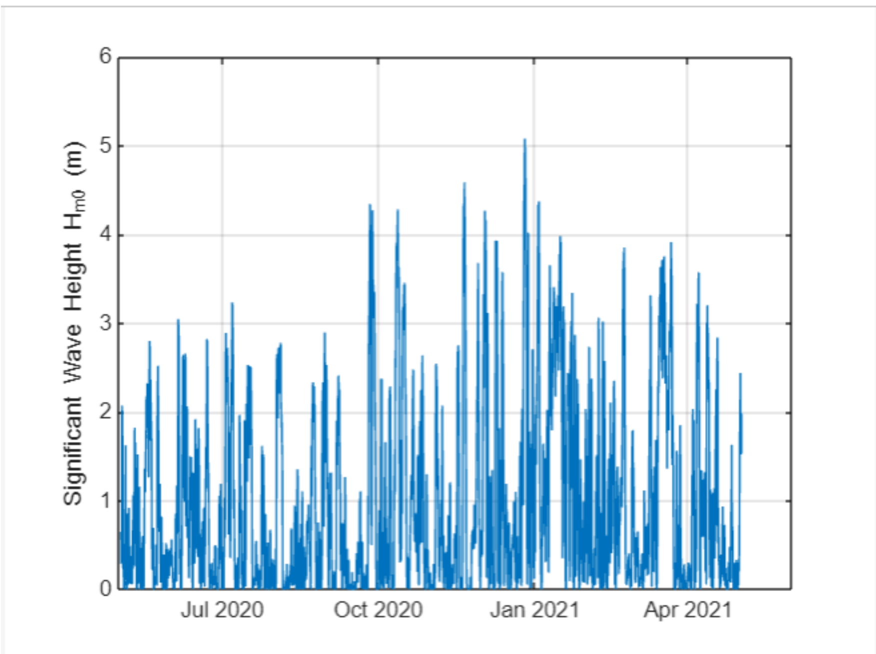


Name	Value	Size
Hm0	1x1x8761 do...	1x1x8761
Tp	1x1x8761 do...	1x1x8761
lat	42.3125	1x1
long	4.0833	1x1
time	8761x1 double	8761x1

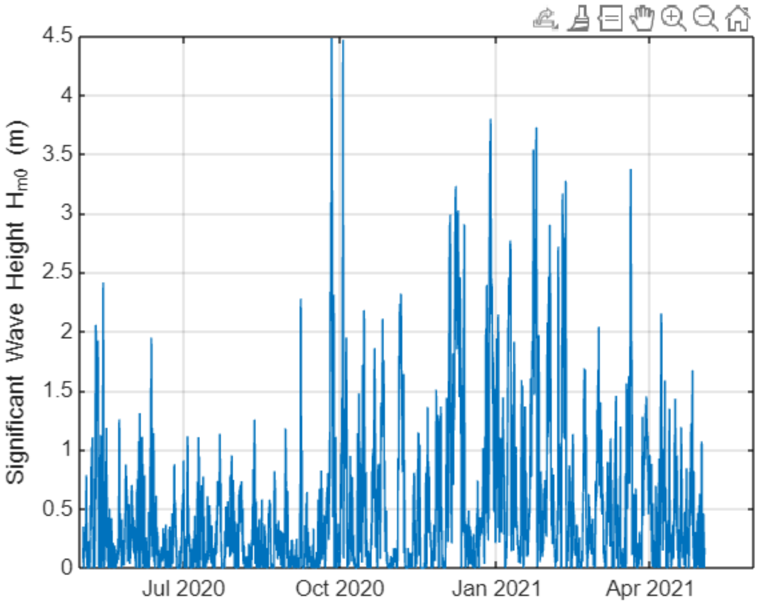


Name	Value	Size
Hm0	8761x1 double	8761x1
Tp	8761x1 double	8761x1

The plot illustrates a time series of the significant wave height Hm0 at the selected point over the reference time period **from Feb 5th 2020 to Feb 5th 2021.**



Location 1 - significant wave height



Location 2 - significant wave height

Scatter Matrix

- Input data:

Hm0 max

Tp max

- To build the scatter matrix we need to define a range for Hm0 and Tp considering their max values:

Hedges = 0:0.2:Hm0 max

Tedges = 1:0.5:Tp max

doing that we are creating a vector that goes:

- **from 0 to Hm0 max** with intervals of 0.2m of discretization for the height (Hs)

- **from 1 to Tp max** with interval of 0.5 s of discretization for the time (Tp)

[N,Hedges,Tedges] = histcounts2(Hm0,Tp,Hedges,Tedges);

The function histcounts2 divides a dataset into beans, in our case is defined by the vectors Hedges and Tedges.

N gives a description of how many sea states fall between the given intervals of Hm0 and Tp. In particular N is the matrix composed by the number of hours in which a given sea state occur in one year. To plot it, the command **meshgrid** and function **pcolor** was used, it returns 2D coordinates based on the coordinates contained in vectors Tedges and Hedges.

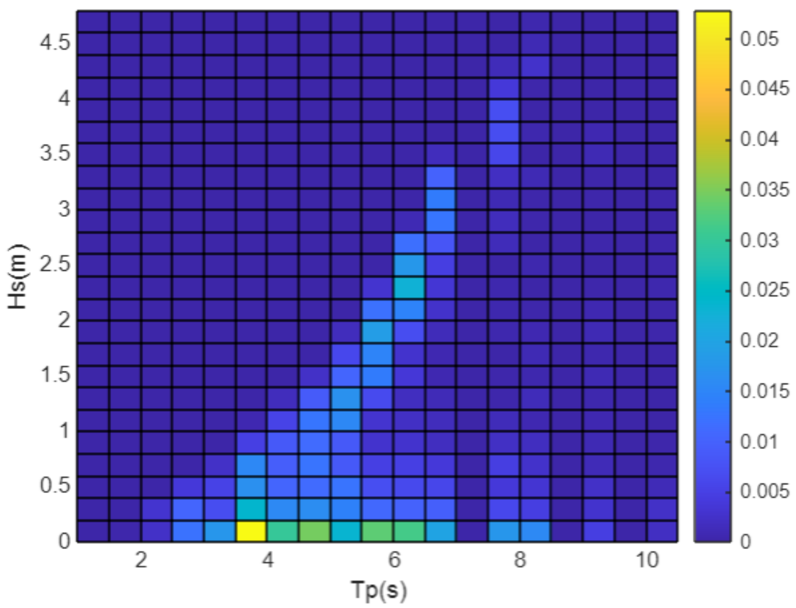
N

25x20 double

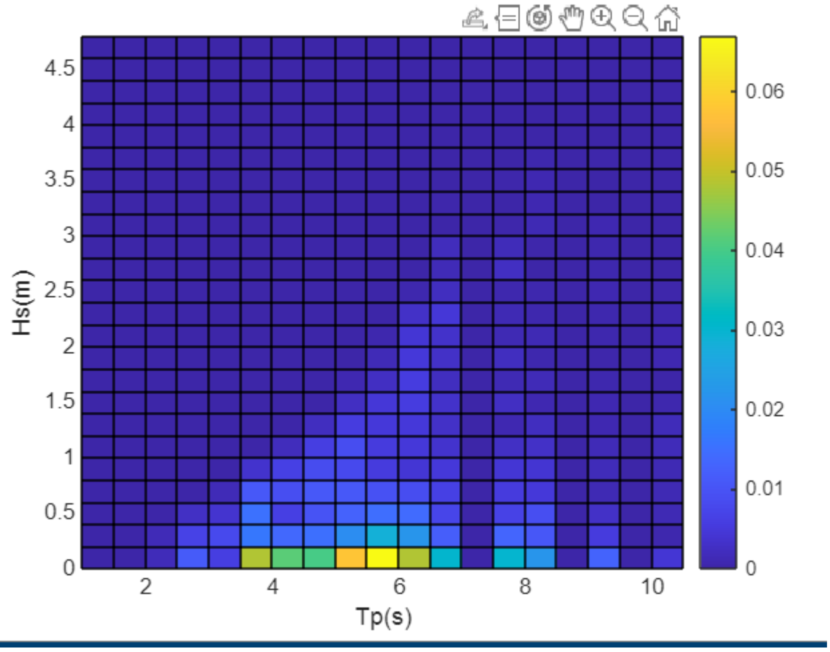
	1	2	3	4	5	6	7	8	9	10	11	12
1	0	3	21	108	155	463	263	303	205	290	275	174
2	0	0	26	92	60	208	136	142	125	95	87	85
3	0	0	0	33	46	145	91	99	109	62	56	52
4	0	0	0	0	20	135	83	109	76	43	43	34
5	0	0	0	0	0	42	77	98	77	25	24	16
6	0	0	0	0	0	7	48	111	134	27	19	13
7	0	0	0	0	0	0	13	79	148	57	16	10
8	0	0	0	0	0	0	0	21	91	119	31	6
9	0	0	0	0	0	0	0	0	54	129	25	6
10	0	0	0	0	0	0	0	0	13	165	61	12
11	0	0	0	0	0	0	0	0	0	105	128	23
12	0	0	0	0	0	0	0	0	0	26	199	29
13	0	0	0	0	0	0	0	0	0	0	156	40
14	0	0	0	0	0	0	0	0	0	0	104	72
15	0	0	0	0	0	0	0	0	0	0	9	111

N matrix

plotting the data we get the **scatter matrix** for the first location:



Location 1



Location 2

DENTIFY THE MOST FREQUENT SEA STATE RANGE FOR THEREFERENCE PERIOD.

In the scatter matrix we have the X-axis corresponding to intervals of peak periods (Tp) and the Y-axis corresponding to intervals of the significant wave height (Hs), so the ranges that we have defined before using Tedges and Hedges. The intensity of the colours in each square is related to the probability (pi) that a given sea state, so a couple of significant wave height and peak periods, falls between 2 given ranges of Tp and Hs. The yellow square has the highest probability of occurrence.

For our 2 locations we identify the most frequent sea-state in the reference period (1 year):

1. **Location 1:**
- Tp = (3.5;4) s
- Hs = (0.0;0.2) m
2. **Location 2:**
- Tp = (4.5;6) s
- Hs = (0.0;0.2) m

As supposed the 2 locations of Mediterranean Sea are characterized by the same most frequent sea-state with much shorter peak periods and significant wave height respect to the Ocean.

3. BUILT THE JONSWAP SPECTRUM WITH THE MID VALUES (Hs AND Tp) OF THE MOST FREQUENT ENERGETIC SEA STATE RANGE AND THE CORRESPONDING IRREGULAR WAVE

Jonswap Spectrum

The Jonswap spectrum (Joint North Sea Wave Project) is a mathematical model used to describe the properties of sea waves. It describes how energy is distributed on waves of different frequencies.

In order to build the Jonswap Spectrum, it is necessary to find the mid values of Hs and Tp:

1. Locaton 1:

- Tp = 3.75 s

- Hs = 0.2 m

2. Location 2:

- Tp = 5.25 s

- Hs = 0.2 m

The JONSWAP spectrum is described by the formula:

$$S(f) = \alpha \frac{5}{16} \frac{H_s^2}{T_p^4} \frac{1}{f^5} e^{-\frac{5}{4}\frac{1}{(T_p f)^4}} \gamma^{e^{\frac{(fT_p - 1)^2}{2\sigma^2}}}$$

where **α** is the coefficient related to wind and fetch characteristics and **γ** is the frequency spreading coefficient:

In general, for Mediterranean Sea:

$$\alpha = 0.076 \left(\frac{U_{10}^2}{Fg} \right)^{0.22}$$

where U_{10} the wind speed at a height of 10 m and F the distance from a lee shore, called the fetch, or the distance over which the wind blows with constant velocity.

Used parameters provided by literature valid for Mediterranean Sea:

σ = 0.07 if f < 1/Tp and σ = 0.09 if f > 1/Tp and γ = 3.3

Irregular wave

The irregular wave corresponding to the spectrum can be obtained as the sum of the different frequencies contributions:

$$\eta(x,t) = \Sigma_i a_i \sin(k_i x - f_i t - \phi_i)$$

Where:

- ai = sqrt(2 S(fi)Δf);
- ki is the wave number (obtained with the dispersion relation considering a time averaged water depth of 21 m)
- ϕi is a random difference in phase.

With the **dispersion relation**, you can get the value of L (wavelength), k (wave number), sigma (wave angular frequency), using different solutions of the dispersion equation.

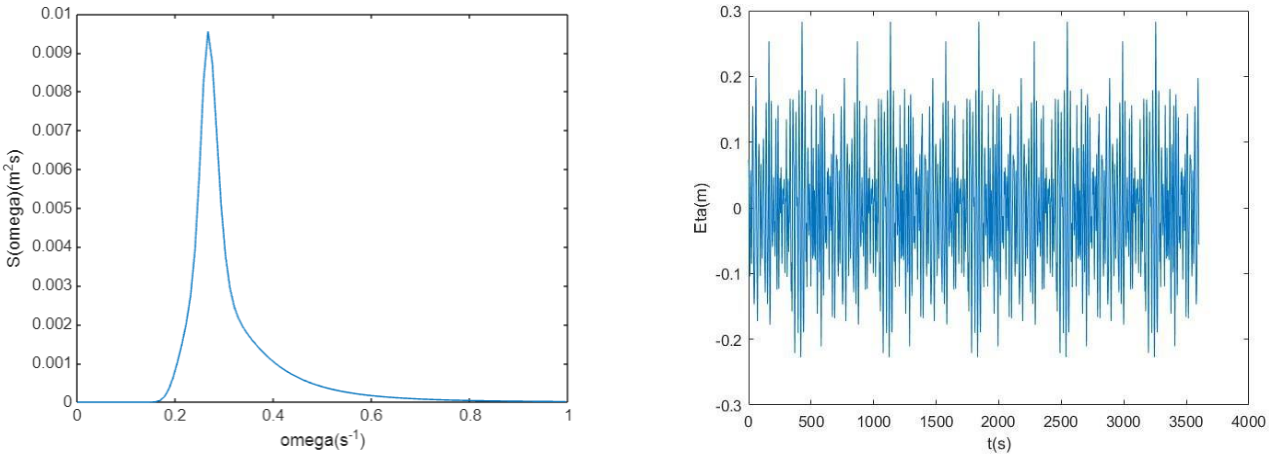
The solution process requires some kind of iterative approach (trial & error) since there are unknown on both sides of the equation. We solved it by using Eckhart's equations.

Inputs:

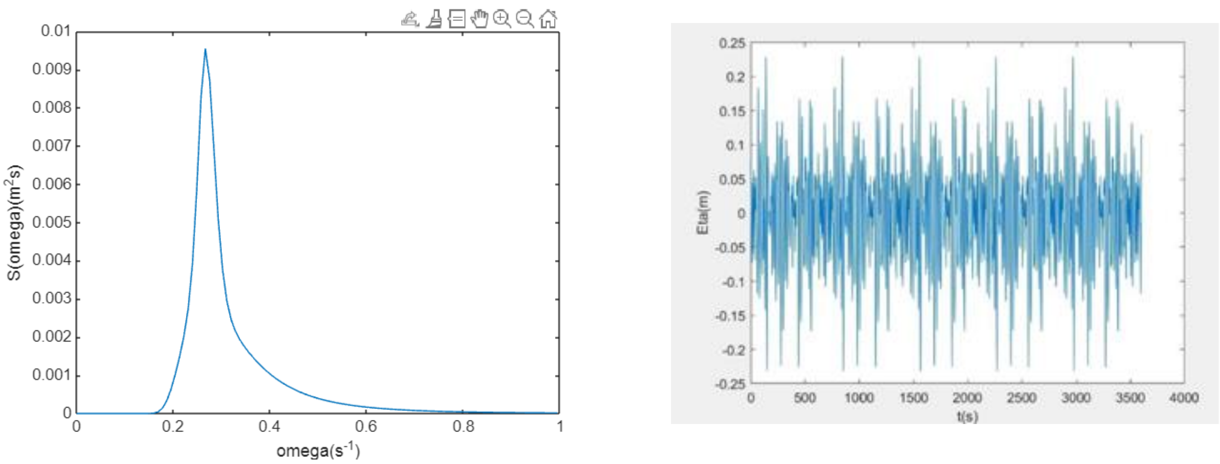
- h = deep water (m)

- Tp = wave peak period (s)

Jonswap spectrum and the corresponding irregular wave for the 3 different locations are reported in the figures below:



Location 1 - Jonswap spectrum and corresponding irregular wave



Location 2- Jonswap spectrum and corresponding irregular wave

5. COMPARE THE DIFFERENT JONSWAP SPECTRA OBTAINED BY THE DIFFERENT MEMBERS OF THE TEAM

S(f) is a measure of the amount of energy contained in the wave per unit frequency interval. It describes how the energy of the wave is distributed over different frequencies.

The spectrum for the first 2 locations, having the same Tp in the most frequent energetic sea-state and therefore the same wave frequency (1/Tp), has the same value of the Spectral Peak. It means that they have the same energy at a given frequency; indeed, being both locations situated in relatively calm seas (Ligurian and Tyrrhenian), confined and more naturally constrained respect to the ocean are characterized by smaller wave height and few energy.

In fact, if we check the spectrum for the third location is characterized by higher Tp (i.e. lower frequency at which we have Spectrum peak) and higher value of S(f) for this frequency.

The ocean is characterized by higher wave heights and different winds that can affect the energy production of the WEC.

An important factor to take into account is the difference in the wave generation provided by the wind and in particular the size and the development of the "fetch", that is a region of the sea on which the wind blows without obstacles, on whose length depends the size of the wave generated.

In the ocean we have different winds generating important fetch, so a lot of distance useful to increase the height of the wave; instead in Italian seas it can be affected by the natural restraint that influence the blowing of the winds and affect the wave propagation and development towards the shore.

This can be an important element to consider in the design phase choosing the proper location to optimize the total energy produced by the waves.

6. EVALUATE THE ANNUAL ENERGY PRODUCTION

In order to calculate the annual energy production (AEP) for the reference Wave Energy Converter we have to apply the formula:

$$AEP = \Sigma_i p_i P_{WEC,i} T_{year}$$

Where

- **p_i**: occurrence probability, as annual time fraction of the occurrence of each sea state
- **$P_{WEC,i}$**: available power for the i-th sea state, with occurrence probability pi, estimated as:

$$P_{wave-i} \simeq 0.4 H_{s-i}^2 T_{p-i} \text{ or } P_{wave-i} \simeq \frac{1}{2} H_{s-i}^2 T_{e-i}$$

- **Tyear**: reference time (one year in hours)

The annual variation in sea states is represented by the scatter matrix, represented in matlab by the matrix N; this matrix that we already created in chapter 3 has values that represents how many hours a specific sea state occurred in one year. From the N matrix, it is possible to create the **probability matrix (pi)**, by dividing each value of N by the hours in one year (in our case 8761hours).

N

25x20 double

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	3	21	108	155	463	263	303	205	290	275	174
2	0	0	26	92	60	208	136	142	125	95	87	85
3	0	0	0	33	46	145	91	99	109	62	56	52
4	0	0	0	0	20	135	83	109	76	43	43	34
5	0	0	0	0	0	42	77	98	77	25	24	16
6	0	0	0	0	0	7	48	111	134	27	19	13
7	0	0	0	0	0	0	13	79	148	57	16	10
8	0	0	0	0	0	0	0	21	91	119	31	6
9	0	0	0	0	0	0	0	0	54	129	25	6
10	0	0	0	0	0	0	0	0	13	165	61	12
11	0	0	0	0	0	0	0	0	0	105	128	23
12	0	0	0	0	0	0	0	0	0	26	199	29
13	0	0	0	0	0	0	0	0	0	0	156	40
14	0	0	0	0	0	0	0	0	0	0	104	72
15	0	0	0	0	0	0	0	0	0	0	9	111

N matrix

probability_matrix

22x20 double

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0.0003	0.0024	0.0123	0.0177	0.0528	0.0300	0.0346	0.0234	0.0331	0.0314	0.0199
2	0	0	0.0030	0.0105	0.0068	0.0237	0.0155	0.0162	0.0143	0.0108	0.0099	0.0097
3	0	0	0	0.0038	0.0053	0.0166	0.0104	0.0113	0.0124	0.0071	0.0064	0.0059
4	0	0	0	0	0.0023	0.0154	0.0095	0.0124	0.0087	0.0049	0.0049	0.0039
5	0	0	0	0	0	0.0048	0.0088	0.0112	0.0088	0.0029	0.0027	0.0018
6	0	0	0	0	0	0.0008	0.0055	0.0127	0.0153	0.0031	0.0022	0.0015
7	0	0	0	0	0	0	0.0015	0.0090	0.0169	0.0065	0.0018	0.0011
8	0	0	0	0	0	0	0	0.0024	0.0104	0.0136	0.0035	0.0007
9	0	0	0	0	0	0	0	0	0.0062	0.0147	0.0029	0.0007
10	0	0	0	0	0	0	0	0	0.0015	0.0188	0.0070	0.0014
11	0	0	0	0	0	0	0	0	0	0.0120	0.0146	0.0026
12	0	0	0	0	0	0	0	0	0	0.0030	0.0227	0.0033
13	0	0	0	0	0	0	0	0	0	0	0.0178	0.0046
14	0	0	0	0	0	0	0	0	0	0	0.0119	0.0082
15	0	0	0	0	0	0	0	0	0	0	0.0010	0.0127

Probability matrix (pi) = N/8761

$P_{WEC,i}$ in our case is represented by the given **Power Matrix**, it collects the power production of the WEC for each sea-state range

power_matrix

22x20 double

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0.1000	0.0800	0.1200
4	0	0	0	0	0	0	0	0.0600	0.1100	0.1600	0.2100	0.3200
5	0	0	0	0	0	0.0600	0.0800	0.1200	0.1500	0.2200	0.3500	0.4000
6	0	0	0	0.0700	0.0500	0.0600	0.1300	0.1800	0.2100	0.3100	0.4700	1.0100
7	0	0	0.0100	0.1100	0.1600	0.2100	0.2300	0.2700	0.2900	0.4100	0.6300	0.9000
8	0	0.1200	0.0900	0.1700	0.3100	0.2700	0.3100	0.3300	0.3700	0.6300	0.8100	1.4200
9	0	0.1700	0.2100	0.2300	0.3100	0.3200	0.3300	0.3500	0.4300	0.7200	1.3700	1.3900
10	0	0.2300	0.2500	0.2900	0.3100	0.3400	0.3300	0.4100	0.5700	1.0000	1.4100	1.4600
11	0	0	0	0	0	0	0	0	0	0	1.5200	1.5700
12	0	0	0	0	0	0	0	0	0	0	1.7800	1.8200
13	0	0	0	0	0	0	0	0	0	0	2.2500	2.4500
14	0	0	0	0	0	0	0	0	0	0	2.8100	3.0100
15	0	0	0	0	0	0	0	0	0	0	3.2700	3.4400

Power Matrix

In order to multiply scalarly each value between the probability matrix (pi) and the Power matrix (Pwec) is fundamental to have the same resolution, so we arranged the size of the 2 to allow this product.

To do this we extended the P_{WEC} dimensions adding zeros in the ranges needed, considering as a precaution that in these conditions the device does not produce energy.

ppm

22x20 double

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0.0007	0.0005	0.0007
4	0	0	0	0	0	0	0	0.0007	0.0010	0.0008	0.0010	0.0012
5	0	0	0	0	0	0.0003	0.0007	0.0013	0.0013	0.0006	0.0010	0.0007
6	0	0	0	0	0	0.0000	0.0007	0.0023	0.0032	0.0010	0.0010	0.0015
7	0	0	0	0	0	0	0.0003	0.0024	0.0049	0.0027	0.0012	0.0010
8	0	0	0	0	0	0	0	0.0008	0.0038	0.0086	0.0029	0.0010
9	0	0	0	0	0	0	0	0	0.0027	0.0106	0.0039	0.0010
10	0	0	0	0	0	0	0	0	0.0008	0.0188	0.0098	0.0020
11	0	0	0	0	0	0	0	0	0	0	0.0222	0.0041
12	0	0	0	0	0	0	0	0	0	0	0.0404	0.0060
13	0	0	0	0	0	0	0	0	0	0	0.0401	0.0112
14	0	0	0	0	0	0	0	0	0	0	0.0334	0.0247
15	0	0	0	0	0	0	0	0	0	0	0.0034	0.0436

Produced power matrix

7. COMPARE THE ANNUAL ENERGY PRODUCTION IN DIFFERENT LOCATION

To obtain the final value of energy produced by each WEC we have to multiply the power produced by the hour in the year (**Tyear**):

1. **Location 1: Passon Andar**

AEP = 3400 kWh

2. **Location 2: Qudratullah Ramzi**

AEP = 2012 KWh

As previously hypothesized the WEC located in the ocean (Location 1) higher amount of energy than the second location in the considered reference period.

Matlab Codes:

```
ncdisp("med-hcmr-wav-rean-h_Passon1711286785622.nc")
Source:
           /MATLAB Drive/med-hcmr-wav-rean-h_Passon1711286785622.nc
Format:
           netcdf4
Global Attributes:
           Conventions      = "CF-1.11"
           title            = "Wave fields (2D) - Hourly Instantaneous"
           institution      = "Hellenic Centre for Marine Research (HCMR)- Athens,Greece"
           producer         = "CMEMS-MED Monitoring and Forecasting Centre"
           source           = "MEDWAM3"
           credit           = "Copernicus Marine Environment Monitoring Service (CMEMS)"
           contact          = "servicedesk.cmems@mercator-ocean.eu"
           references       = "Please check in CMEMS catalogue the INFO section for product
MEDSEA_MULTIYEAR_WAV_006_012 - http://marine.copernicus.eu"
           comment          = "Please check in CMEMS catalogue the INFO section for product
MEDSEA_MULTIYEAR_WAV_006_012 - http://marine.copernicus.eu"
           subset:source    = "ARCO data downloaded from the Marine Data Store using the MyOcean Data
Portal"
           subset:productId = "MEDSEA_MULTIYEAR_WAV_006_012"
           subset:datasetId = "med-hcmr-wav-rean-h_202105"
           subset:date      = "2024-03-24T13:26:25.624Z"
Dimensions:
           latitude  = 1
           longitude = 1
           time      = 8761
Variables:
    VHM0_WW
           Size:       1x1x8761
           Dimensions: longitude,latitude,time
           Datatype:   single
           Attributes:
                       units         = "m"
                       _FillValue    = NaN
                       standard_name = "sea_surface_wind_wave_significant_height"
                       long_name     = "Spectral significant wind wave height"
    VTPK
           Size:       1x1x8761
           Dimensions: longitude,latitude,time
           Datatype:   single
           Attributes:
                       units         = "s"
                       _FillValue    = NaN
                       standard_name = "sea_surface_wave_period_at_variance_spectral_density_maximum"
                       long_name     = "Wave period at spectral peak / peak period (Tp)"
    latitude
           Size:       1x1
           Dimensions: latitude
           Datatype:   single
           Attributes:
                       standard_name = "latitude"
                       long_name     = "Latitude"
                       units         = "degrees_north"
                       unit_long     = "Degrees North"
                       axis          = "Y"
                       valid_min     = 30.1875
                       valid_max     = 45.9792
    longitude
           Size:       1x1
           Dimensions: longitude
           Datatype:   single
           Attributes:
                       standard_name = "longitude"
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                        long_name     = "Longitude"
                        units         = "degrees_east"
                        unit_long     = "Degrees East"
                        axis          = "X"
    time
           Size:       8761x1
           Dimensions: time
           Datatype:   double
           Attributes:
                        standard_name = "time"
                        long_name     = "Time"
                        units         = "seconds since 1970-01-01 00:00:00"
                        calendar      = "gregorian"
                        axis          = "T"
lat = ncread('med-hcmr-wav-rean-h_Passon1711286785622.nc','latitude');
long = ncread('med-hcmr-wav-rean-h_Passon1711286785622.nc','longitude');
time = ncread('med-hcmr-wav-rean-h_Passon1711286785622.nc','time');
Hm0 = ncread('med-hcmr-wav-rean-h_Passon1711286785622.nc','VHM0_WW');
Tp = ncread('med-hcmr-wav-rean-h_Passon1711286785622.nc','VTPK');

date = datetime(time,'ConvertFrom','posixtime');
 Hm0 = squeeze(Hm0);
Tp = squeeze(Tp);
plot(date,Hm0); grid on
ylabel('Significant Wave Height H_{m0} (m)');


maxHm0= max(Hm0);
maxTp = max(Tp);
Hedges = 0:.2:5.077;
Tedges = 1:.5:11.167;
[N,Hedges,Tedges] = histcounts2(Hm0,Tp,Hedges,Tedges);
 [T,H] = meshgrid(Tedges(1:end-1),Hedges(1:end-1));
p = pcolor(T,H,N/numel(Hm0));
colorbar;
xlabel('Tp(s)')
ylabel('Hs(m)')


%sea_state_plots - jonswap spectrum
Hs=0.1;%m
Tp=3.75;%s
alpha=0.862; % ParunovEtAl_OE2011
omega_p = 1/Tp;
omega_max=1; %(qualitative threshold of gravity wave);
d_omega=(1/Tp)/30;
omega_vett=[0:d_omega:omega_max];
sigma = (omega_vett<=omega_p)*0.07+(omega_vett>omega_p)*0.09;
gamma = 3.3; % ParunovEtAl_OE2011
fac1=alpha*(5/16)*(Hs^2)/(Tp^4);
fac2=omega_vett.^-5;
fac3=exp(-(5/4)*(omega_vett*Tp).^-4);
Aa = exp(-((omega_vett*Tp-1)./(sigma*sqrt(2))).^2);
fac4 = gamma.^Aa;
S_vett = fac1.*fac2.*fac3.*fac4;
S_vett(1)=0;
plot(omega_vett,S_vett);
xlabel('omega(s^-^1)')
ylabel('S(omega)(m^2s)')


h=21;%m
T=3.75;
```

```
x0 =0.0001;
Lr=0;
if sign(h) == -1
h = -h;
end
X=0;
t_vett=0:dt:60*60;


dt=0.1;
h=21;%m
T=3.75;
x0 =0.0001;
Lr=0;
if sign(h) == -1
h = -h;
end
X=0;
t_vett=0:dt:60*60;
Lr=0;
ke = sigma/(9.81*sqrt(tanh(h*(sigma/9.81))));
Le = (2*pi)/ke;
Ce = Le/T;
ne =0.5*(1+((2*ke*h)/sinh(2*ke*h)));
Cge = ne * Ce;
ee = (abs(Lr-Le)/abs(Lr))*100;
phi=2*pi*rand(1,numel(omega_vett));
for index=1:numel(omega_vett)
a(index)=sqrt(2*S_vett(index)*d_omega);
[L(index),k(index),sigma(index)]=disper(h,1/omega_vett(index));
eta(index,:)=a(index)*sin(k(index)*X-omega_vett(index)*t_vett - phi(index));
end

Lr=0;
ke = sigma/(9.81*sqrt(tanh(h*(sigma/9.81))));
Le = (2*pi)/ke;
Ce = Le/T;
ne =0.5*(1+((2*ke*h)/sinh(2*ke*h)));
Cge = ne * Ce;
ee = (abs(Lr-Le)/abs(Lr))*100;
phi=2*pi*rand(1,numel(omega_vett));
for index=1:numel(omega_vett)
a(index)=sqrt(2*S_vett(index)*d_omega);
eta(index,:)=a(index)*sin(k(index)*X-omega_vett(index)*t_vett - phi(index));
end
eta_seastate=sum(eta,1);
plot(t_vett,eta_seastate);
xlabel('t(s)')
ylabel('Eta(m)')

dt=0.1;
h=21;%m
T=3.75;
x0 =0.0001;
Lr=0;
if sign(h) == -1
h = -h;
end
X=0;
t_vett=0:dt:60*60;
[Lr,kr,sigma]=disper(h,T)
% *********** Solving dispersion equation, using Eckhart **********
Lr=0;
```

```
ke = sigma/(9.81*sqrt(tanh(h*(sigma/9.81))));
Le = (2*pi)/ke;
Ce = Le/T;
ne =0.5*(1+((2*ke*h)/sinh(2*ke*h)));
Cge = ne * Ce;
ee = (abs(Lr-Le)/abs(Lr))*100;
phi=2*pi*rand(1,numel(omega_vett));
for index=1:numel(omega_vett)
a(index)=sqrt(2*S_vett(index)*d_omega);
eta(index,:)=a(index)*sin(k(index)*X-omega_vett(index)*t_vett - phi(index));
end
eta_seastate=sum(eta,1);
plot(t_vett,eta_seastate);
xlabel('t(s)')
ylabel('Eta(m)')


power_matrix=readtable("power_matrix.xlsx")
power_matrix = removevars(power_matrix, ["Var1","Var2","Var3"]);
power_matrix(1:3,:) = [];
power_matrix=table2array(power_matrix)
power_matrix(isnan(power_matrix)) = 0
probability_matrix= N/8761
probability_matrix(end-2, :) = []; as needed
ppm = probability_matrix.*power_matrix
average_power=sum(ppm(:))
AEP = average_power*8761
```