Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment

Deliverable D5.2

Site Characterisation – alpha version

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EXECUTIVE SUMMARY

Deliverable D5.2 "Site Characterisation – alpha version" of the DTOceanPlus project include the details of the Deployment Tool module: "Site Characterisation" (SC), and it represents the result of the work developed during the task 5.3 of the project.

This document summarises both the functionalities as well as the more technical aspects of the code implemented for this module.

In order to fill one of the gaps of the existing DTOcean toolset, a Site Characterisation tool has been designed and implemented in the DTOceanPlus platform.

The Site Characterisation tool receives as input the environmental data of the chosen site and provides the user the main characteristics of this site in terms of bathymetry, seabed types, marine species, waves, tidal currents, winds and water levels. It includes time series of pertinent parameters as well as statistics on these parameters like probability distributions, scatter diagrams or extreme values.

The Business Logic of the code, i.e. the actual functions of the SC module, has been implemented in Python 3. Moreover, the code is provided with an Application Programming Interface (API), developed in OpenAPI, in order to interact and communicate with the other modules of the DTOceanPlus platform: A Graphical User Interface (GUI) is under development, consistent with the other modules, in Vue.js, allowing the user to interact easily with the SC tool, inputting data and visualising results.

The Business Logic of the code has been fully verified through the implementation of unit tests, guaranteeing easy maintainability for future developments of the tool.

A section of Examples completes the present document, showing the capabilities of the tool.

Finally, future work in discussed, in particular the link to the new database which will be created during the European ResourceCode project.

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ABBREVIATIONS AND ACRONYMS

API	Application Programming Interface
CgE	Wave energy flux
Cp	Current available power
Dp	Wave peak direction (Meteorological convention).
EJPD	Empirical Joint Probability Distribution
ENVS	Environments for fatigue analysis
EPD	Empirical Probability Distribution
EXC	Extreme contours (or environmental contours)
EXT	Extreme value analysis
Gamma	JONSWAP peak shape parameter
GEBCO	General Bathymetric Chart of the Oceans
GUI	Graphical User Interface
Gust10	10m-wind gusts
Ho	Bathymetry (distance from bottom to MSL)
Hs	Significant wave height
Ifremer	Institut Français de Recherche pour l'Exploitation de la MER
Mag	Tidal current magnitude
Mag10	10m-wind magnitude
MSL	Mean sea level
OpenAPI	Language that describes the API
SC	Site Characterisation
SHOM	Service Hydrographique et Océanique de la Marine
Spr	Wave directional spreading
STD	Standard deviation of a variable
Te	Wave energy period
Theta	Tidal current direction (Oceanographical convention)
Theta10	10m-wind direction (Meteorological convention)
Tp	Wave peak period
WLEV	Water level, relative to the bottom (XE+Ho)
XE	Water surface fluctuation, relative to MSL

1. INTRODUCTION

1.1 SCOPE AND OUTLINE OF THE REPORT

Deliverable 5.2 "Site Characterisation – alpha version" of the DTOceanPlus project includes the details of the Deployment Design Tools module: "Site Characterisation" (SC), and it represents the result of the work developed during the task 5.3 of the project.

In order to fill one of the gaps of the existing DTOcean toolset, a SC tool has been designed and implemented in the DTOceanPlus platform.

The SC tool receives as input the environmental data (bathymetry, sea weather climate, etc.) of the site and outputs post-processed data to the other tools and to the user for direct visualisation.

It was originally planned to couple the DTOceanPlus toolset with TELEMAC-MASCARET, a suite of solvers for use in the field of free-surface flow, but due to the withdrawal of one of the partners, it could not be done.

However, the user can import his own database into the SC module and thus obtain precise results at his site of interest.

This document summarises:

1) The use cases and the functionalities of the Site Characterisation tool, provide the user with the physical characteristics of the site: waves, tidal currents, winds and water levels (Section 2).
2) The actual implementation of the tool, describing the architecture of the tool, the technologies adopted for the implementation and the results of the testing (Section 4).
3) A set of extensive examples, to provide the reader with an overall view of the capabilities of the tools (Section 5).

1.2 SUMMARY OF THE DTOCEANPLUS PROJECT

The Site Characterisation tool belong to the platform of tools "DTOceanPlus" developed within the EU-funded project DTOceanPlus (https://www.dtoceanplus.eu/).

DTOceanPlus will accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open source suite of design tools for the selection, development, deployment and assessment of ocean energy systems (including sub-systems, energy capture devices and arrays).

At a high level, the suite of tools developed in DTOceanPlus will include:

- **Structured Innovation Tool (SI)**, for concept creation, selection, and design.
- **Stage Gate Tool (SG)**, using metrics to measure, assess and guide technology development.
- **Deployment Tools**, supporting optimal device and array deployment:
    - Site Characterisation (SC): to characterize the site, including metocean, geotechnical, and environmental conditions.

- Machine Characterisation (MC): to characterize the prime mover;
- Energy Capture (EC): to characterize the device at an array level;
- Energy Transformation (ET): to design PTO and control solutions;
- Energy Delivery (ED): to design electrical and grid connection solutions;
- Station Keeping (SK): to design moorings and foundations solutions;
- Logistics and Marine Operations (LMO): to design logistical solutions and operation plans related to the installation, operation, maintenance, and decommissioning operations.

- **Assessment Tools**, to quantify key parameters:
  - System Performance and Energy Yield (SPEY): to evaluate projects in terms of energy performance.
  - System Lifetime Costs (SLC): to evaluate projects from the economic perspective.
  - System Reliability, Availability, Maintainability, Survivability (RAMS): to evaluate the reliability aspects of a marine renewable energy project.
  - Environmental and Social Acceptance (ESA): to evaluate the environmental and social impacts of a given wave and tidal energy projects.

These will be supported by underlying common digital models and a global database, as shown graphically in Figure 1-1.

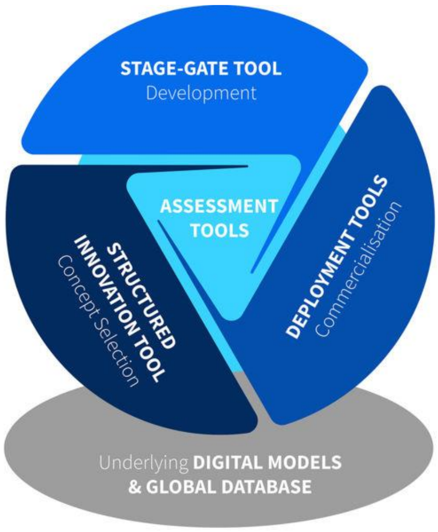


FIGURE 1-1: REPRESENTATION OF DTOCEANPLUS TOOLS.

2. BACKGROUND

The aim of the SC module is to characterise an MRE site for the deployment of a technology.

To characterise an MRE site (WEC or TEC in our case), it is necessary to characterise the "static" parameters of the site (bathymetry, bottom sediment type, presence or not of endangered species), but also the "temporal" parameters, including a faster evolution (waves, currents, winds and water levels). The latter will therefore be characterised by time series, but also by statistics making it possible to understand or predict their evolution.

The results of the SC module will therefore serve as inputs to the other modules of the DTOceanPlus suite and may also be used directly for the user who wishes to obtain information on a given site.

3. USE CASES AND FUNCTIONALITIES

The Site Characterisation (SC) module will:

- Extract 1D direct values (no temporal dimension) from databases (DTOcean+ ones or user inputs), like bathymetry, bottom sediment types or endangered marine species;
- Extract 1D (punctual) or 2D (longitude/latitude) temporal data from physical databases (DTOcean+ ones or user inputs), like waves or currents databases;
- Compute statistics on these databases.

3.1 THE USE CASES

The User can:

1) Run the SC module before running the set of Deployment Design tools of DTOceanPlus.
2) Use the SC module in standalone mode.

Table 3-1 summarises the dependencies of SC to other modules in DTOceanPlus; note that SC is the first module to be run and therefore does not need any service from other modules.

TABLE 3-1: DEPENDENCIES OF SC FROM/TO OTHER MODULES IN DTOCEANPLUS.

Modules that provide services that SC consumes	Modules that are consuming services from SC
	Energy Capture (EC), Energy Delivery (ED), Station Keeping (SK), Logistics & Marine Operations (LMO), Environmental and Social Impact (ESA), System Performance Energy Yield (SPEY)

3.1.1 USE CASE BEFORE DEPLOYMENT DESIGN TOOLS

In this case, the User will run SC module in order to set up the site characteristics and then they will run one or more Deployment Design Tools. The user will be asked to complete the inputs data that is needed to run the module. As a result, graphs of main site characteristics and statistics will be exposed to the user for verification as shown in Figure 3-1.

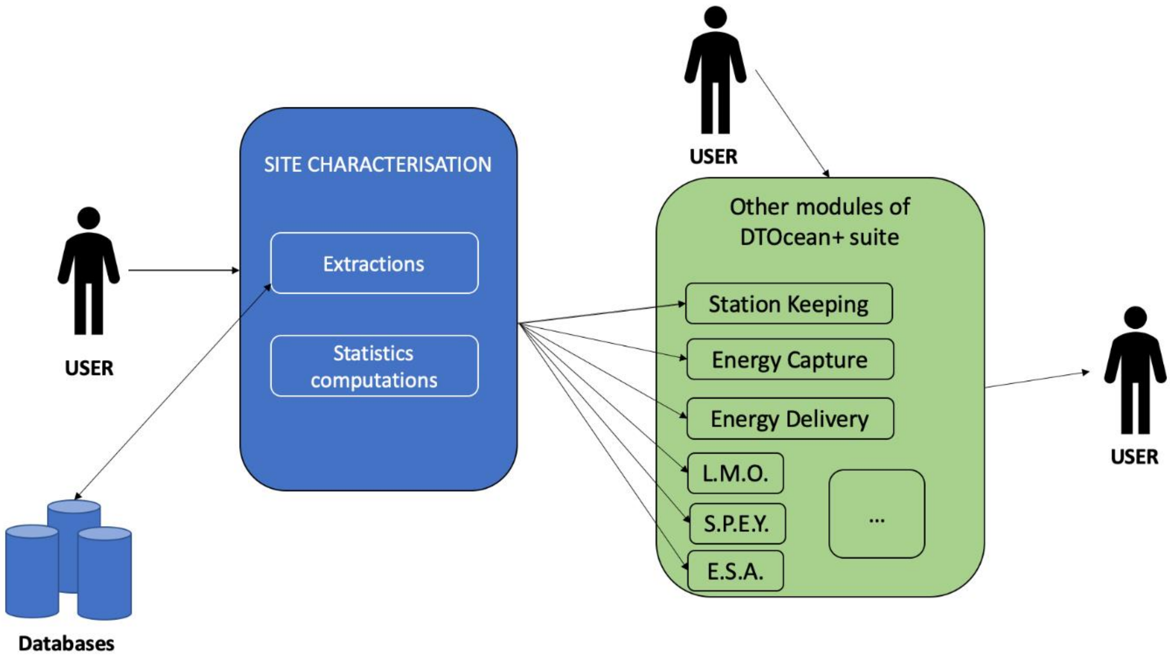


FIGURE 3-1: USE CASE FOR USING THE SITE CHARACTERISATION TOOL BEFORE RUNNING THE DEPLOYMENT DESIGN TOOLS.

3.1.2 STANDALONE MODE

In this case (Figure 3-2), the User will run the SC module in order to know the site characteristics. The user will be asked to complete the inputs data that is needed to run the module. As a result, graphs of main site characteristics and statistics will be exposed to the user for verification as shown in Figure 4-5.

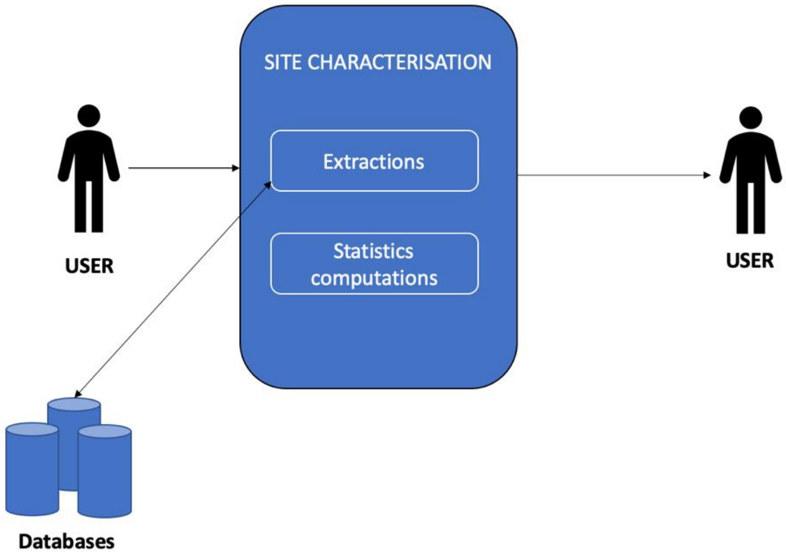


FIGURE 3-2: USE CASE FOR USING THE SITE CHARACTERISATION TOOL STANDALONE.

3.2 THE FUNCTIONALITIES

The SC Module realises the following tasks:

1) **Database extractions:** input databases are selected by the user, and the SC module reads all the input files and extracts the requested variables (section 3.2.1)
2) **Compute statistics based on the extractions**: based on the extracted variables, a list of statistics is computed, from basic ones to multivariate extreme values analysis (section 3.2.2).

To be consistent with the other tools, the level of complexity of the project and for which the assessments can be carried out has also been accounted for. Indeed, during the implementation (see Section 4), this has been considered at three different levels of complexity: A low complexity level (CPX1), an intermediate stage (CPX2) and a full complexity stage (CPX3).

The three levels of complexity produce the same results in terms of computed statistics, but the inputs are different: at complexity level 1, 1D (punctual) databases are proposed to the user who defines the wanted levels of energy for waves and tidal currents; at complexity level 2, 2D (longitude/latitude) databases are proposed to the user who defines the wanted levels of energy for waves and tidal currents, and finally, at complexity level 3, the user can choose his own databases.

The complete execution time of the SC module (extraction + statistics computation) is approximately 10 minutes.

For complexity levels 1 and 2, if the user has already created a site with the requested energy levels, the execution time will be a few seconds.

3.2.1 DATABASES AND EXTRACTIONS

3.2.1.1 Direct values

Some databases are fixed in time, this means that they were created at a given time and they do not include a temporal dimension. The values retrieved from these databases are called "direct values" (for example, the bathymetry or the bottom superficial sediment typology).

These databases and how their variables are extracted are presented below.

Databases

This section presents the direct values databases used in the SC module.

1/ GEBCO_2019:

GEBCO's aim is to provide the most authoritative publicly available bathymetry of the world's oceans. It operates under the joint auspices of the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) (of UNESCO).

The GEBCO_2019 Grid [GEBCO] is the latest global bathymetric product released by the General Bathymetric Chart of the Oceans (GEBCO) and has been developed through the Nippon Foundation-GEBCO Seabed 2030 Project. This is a collaborative project between the Nippon Foundation of Japan and GEBCO. The Seabed 2030 Project aims to bring together all available bathymetric data to produce the definitive map of the world ocean floor and make it available to all.

The Nippon Foundation of Japan is a non-profit philanthropic organisation active around the world. GEBCO is an international group of mapping experts developing a range of bathymetric data sets and data products, operating under the joint auspices of the International Hydrographic Organization (IHO) and UNESCO's Intergovernmental Oceanographic Commission (IOC).

The GEBCO_2019 product provides global coverage (Figure 3-3), spanning 89° 59' 52.5"N, 179° 59' 52.5"W to 89° 59' 52.5"S, 179° 59' 52.5"E on a 15 arc-second grid. It consists of 86400 rows x 43200 columns, giving 3,732,480,000 data points. The data values are pixel-center registered i.e. they refer to elevations at the center of grid cells.

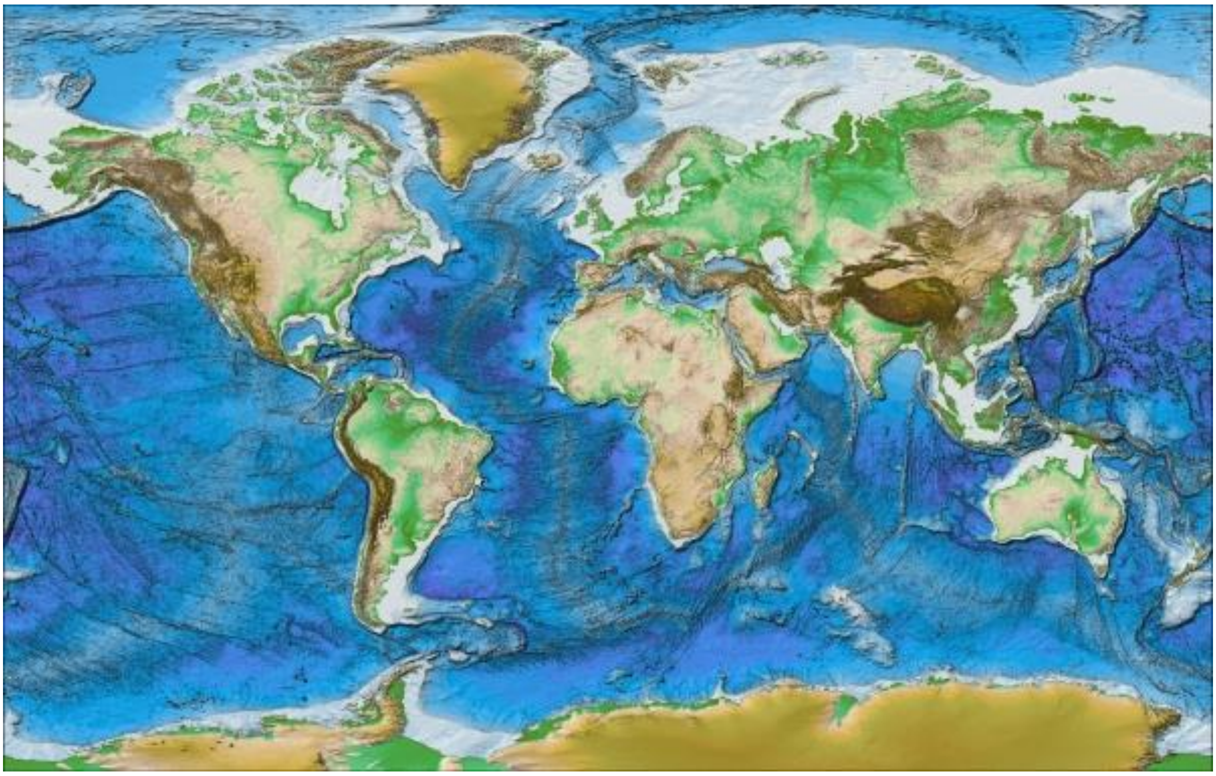


FIGURE 3-3: GEBCO_2019 OVERVIEW.

The variable extracted from this database is ***Ho***, the depth of the water, i.e. the height of water between the bottom and the local mean sea level. The unit associated with the variable is ***m from MSL*** (meters from the mean sea level).

Note that for reasons of disk space, the bathymetry present in the SC module has been degraded (only one mesh out of 20 has been retained).

2/ World Sediment Map (SHOM):

The map of the world [Garlan et al, 2018] is initially based on a map of the oceans entitled Sedimentological Map of the World published by UNESCO, digitised by SHOM in 1995. This fairly coarse map is intended to provide basic information on the nature of all seabed. In the second step, this map was progressively improved by integrating more precise maps, produced by SHOM or digitized from published documents. This version of the world map is the third published version. It includes the cards listed at the end of the manual. These maps are integrated into the world map when their quality and the interest of their content motivated their integration and validation in the SHOM Sedimentological Database (BDSS), and when their scale is less than or equal to 1: 500,000 (Figure 3-4).

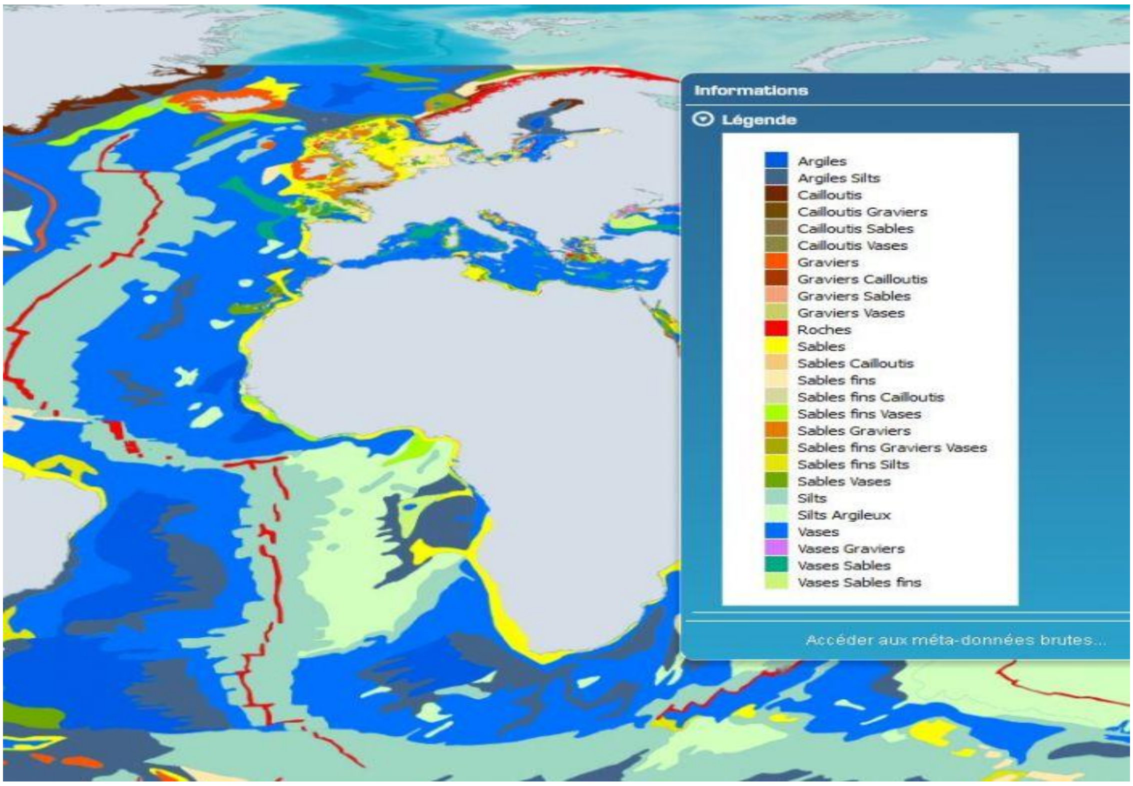


FIGURE 3-4: WORLD SEDIMENT MAP (SOURCE: SHOM).

The variable extracted from this database is ***the type of sediment*** (rocks, pebbles, sands, ...). There is ***no unit*** associated with this variable.

From this database, the macroscopic roughness length ***zo*** is also computed. To do this, we use Nikuradse's formula which says that the gross roughness is equal to 2.5 times the average diameter (D50) of the sediment. ***zo*** is given in ***meters***.

Table 3-2 gives the correspondence between the type of bottom sediment and the macroscopic roughness length.

TABLE 3-2: BOTTOM SEDIMENT TYPES AND ROUGHNESS LENGTH.

Sediment type	D50 [mm]	Zo [m]
Rocks	100	0.250
Peebles	50	0.125
Gravels	10	0.025
Sands	1	0.0025
Fine sands	0.1	0.00025
Mud	0.02	0.00005
No data	0	0

3/ Endangered species:

A local database of maps of large-scale probability of presence for each species is integrated to Site Characterisation module.

This database including the global geographical information of all species has been built from AquaMaps [Kaschner et al., 2016]. This collaborative project aims at producing computer-generated (and ultimately, expert reviewed) predicted global distribution maps for marine species on a 0.5 x 0.5-degree grid of the oceans.

Models are constructed from estimates of the environmental tolerance of a given species with respect to depth, salinity, temperature, primary productivity, and its association with sea ice or coastal areas. Maps represent mean annual distributions of species and do not account for changes in species occurrence due to migration or unusual environmental events such as El Niño. They are based on data available through online species databases such as *FishBase* and *SeaLifeBase* and species occurrence records from OBIS or GBIF and using an environmental envelope model in conjunction with expert input.

More information is available in deliverable D6.5 "Environmental and Social Acceptance Tools - alpha version".

The variable extracted from this database is the ***probability of presence of 26 endangered species*** listed in international and European conventions. The unit associated with the variable is ***%.***

Extraction

The databases we just mentioned are in netCDF format. NetCDF (Network Common Data Form) is a set of software libraries and machine-independent data formats that support the creation, access and sharing of array-oriented scientific data. It is also a community standard for sharing scientific data. The Unidata Program Center supports and maintains netCDF programming interfaces for C, C++, Java and Fortran. NetCDF format is self-describing, portable, scalable, appendable, sharable and archivable.

These netCDF files are stored in a folder of the SC module called "Databases" and are referenced through a Python dictionary.

Data extraction scripts refer to this dictionary according to the user's choices to read the files and extract the necessary variables. This extraction is carried out at the points of the site of interest thanks to the geo-referencing (longitudes and latitudes in WGS84) of the databases.

For certain variables such as Ho (bathymetry), a spatial interpolation is also carried out in order to take into account the points in the vicinity by achieving an average weighted by the distance to the point of interest.

3.2.1.2 Time series

Some databases are time-dependent, that means that they include a temporal dimension with several time steps. The values retrieved from these databases are called "time series" (for example, the significant wave height or the tidal current magnitude).
For complexity levels 1 and 2, the time series are all extracted from the HOMERE database. Indeed, this database which currently covers the coasts of metropolitan France will soon be extended to Europe, from the North of Scotland to the South of Portugal, as part of the ResourceCode project (http://www.emec.org.uk/projects/ocean-energy-projects/tool-development/resourcecode-project/).

This database and how its variables are extracted are presented below.

Databases

HOMERE database was performed by Ifremer using the numerical wave model WaveWatchIII® (WW3) version 4.09 [Boudière et al., 2013]. WW3 is a third-generation spectral wave model based on the conservation equation for the density of wave action.

The propagation scheme used in this configuration is an explicit propagation for unstructured grid [Roland, 2008; Roland, 2009]. The use of unstructured meshes permits to adapt the grid resolution at different scales in the same computational domain, from the coastal zone (refined mesh of ~ 100-200m) to offshore (mesh ~ 10km).

The time step is about 1 hour. It extends from 43.29°N to 52.90°N and from 8.54°W to 4.72°E and covers a period from 1994 to 2016.

The setup used in this configuration for the generation and dissipation of waves [Ardhuin 2009; Ardhuin, 2010] is the one that was developed during the research project IOWAGA (Integrated Ocean Waves for Geophysical Applications) and tested in preparation mode in the context of operational demonstrator Previmer [Lecornu, 2008]. The evolution and nonlinear wave interactions are modelled by the DIA method (Discrete Interaction Approximation) [Hasselmann, 1985].

The simulated sea-state conditions were performed on a high-resolution bathymetry stretching from southern North Sea to the northern coast of Spain, covering the entire continental shelf of the Bay of Biscay. The bathymetry was obtained using data from the SHOM (Hydrographic and Oceanographic Service of the Navy) for the coastline and measurement campaigns conducted by IFREMER and SHOM for the entire field: 100m and 500m DTM [Loubrieu, 2008].

The wind fields used to force the model are from CFSR reanalysis (Climate Forecast System Reanalysis, [Saha, 2010]) conducted in 2010 by the NCEP (National Centres for Environmental Prediction). These wind fields were re-analysed over the period 1979-2009. Their spatial resolution varies from 0.25° at the equator up to 0.5° higher latitudes.

Currents, water levels and storm surges were calculated using the hydrodynamic code MARS2D (Model for Applications at Regional Scale). MARS2D is a model developed by IFREMER [Lazure, 2008] and based on shallow water equations. It consists of seven nested models whose resolution differs according to rank (ranks 0, 1 and 2).

Data from Météo-France were used as meteorological forcing for the model MARS2D. Ranks 0 and 1 are forced using data from meteorological model ARPEGE 0.5° [Broker, 1991; Broker 1994] with a 6-hours' time step. Models of rank 2, with higher resolution, are forced with data from the meteorological model AROME 0.025° [Seity, 2011] with a 1-hour time step.

To make easier the processing of ocean current data and water levels used as inputs by the wave model, an atlas of harmonic components was computed. A replay of tide data was performed over one year (2008) and an analysis of harmonic components of the tide for each of the seven models too. Tides and tidal currents can thus be evaluated for each year over the entire field. Tidal harmonics and water levels are updated every 30 minutes and are interpolated onto the wave model mesh.

A large set of in situ data from various sources, including ocean surveys is at disposal for validation purpose.

Comparison was made with data from the Cetmef CANDHIS buoys network and Météo-France buoys along the French coast.

From this database, several variables are extracted:

- Waves: significant wave height (Hs), wave peak period (Tp), wave peak direction (Dp), wave energy period (Tom1 or Te), wave energy flux (CgE);
- Tidal currents: zonal component of tidal current (Ucur) and meridional component of tidal current (Vcur);
- Winds: zonal component of wind speed (Uwnd) and meridional component of wind speed (Vwnd);
- Water levels: water level fluctuations (Wlev).

For complexity level 1, variables are extracted in 1D, just at the location of interest. For complexity level 2, variables are extracted in 2D, the closest points of the database which are in the area of interest (i.e. the lease area of the project) are extracted.

From the time series database described above, sites representing different levels of energy for waves and currents have been defined; this procedure is described in the following section.

Levels of energy

For the first 2 levels of complexity, the user chooses his site according to the energy levels of the waves and currents he wishes. He can choose 3 energy levels (Low, Medium and High) for waves and the same for currents. There are therefore 9 (3x3) sites representative of the energy levels that are available for the first 2 levels of complexity.

Figure 3-5 shows the 9 sites (HOMERE database) that were selected.

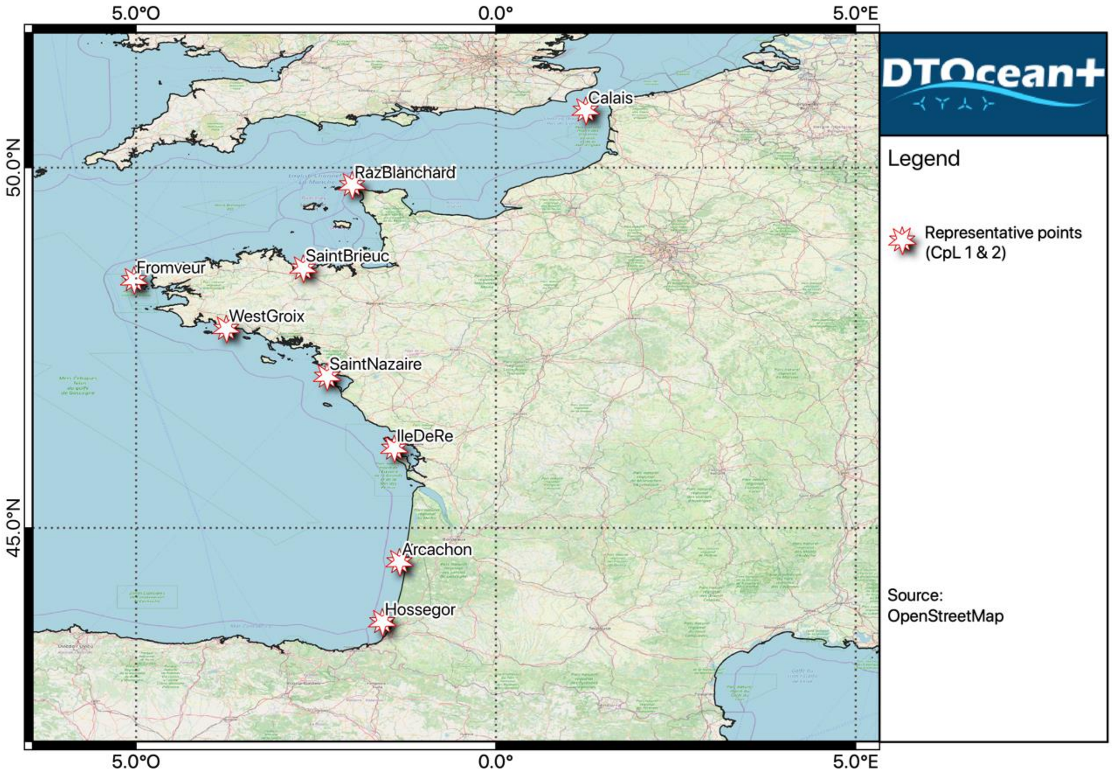


FIGURE 3-5: REPRESENTATIVE POINTS FOR THE 2 FIRST LEVELS OF COMPLEXITY.

At complexity level 1, the extractions are carried out at 1 point on the site (the center of the lease area).

At complexity level 2, the extractions are performed at several points in the 2D database which are located in the lease area. Figure 3-6 shows the points of the HOMERE database (black circles) around a point of interest and also the lease area and the corridor related to this site.

Indeed, for the first 2 levels of complexity, the lease areas and the corridors are automatically defined. For complexity level 3, the user will enter their lease area and their corridor in the form of a shapefile file (ESRI).

For the last level of complexity (level 3), the user will be able to upload their own databases (anywhere in the world), in one or two dimensions (see section 3.2.1.3). Note that the 2-dimensional databases offer more details to the calculations performed by the other modules of the DTOcean+ suite, especially in terms of device placement.

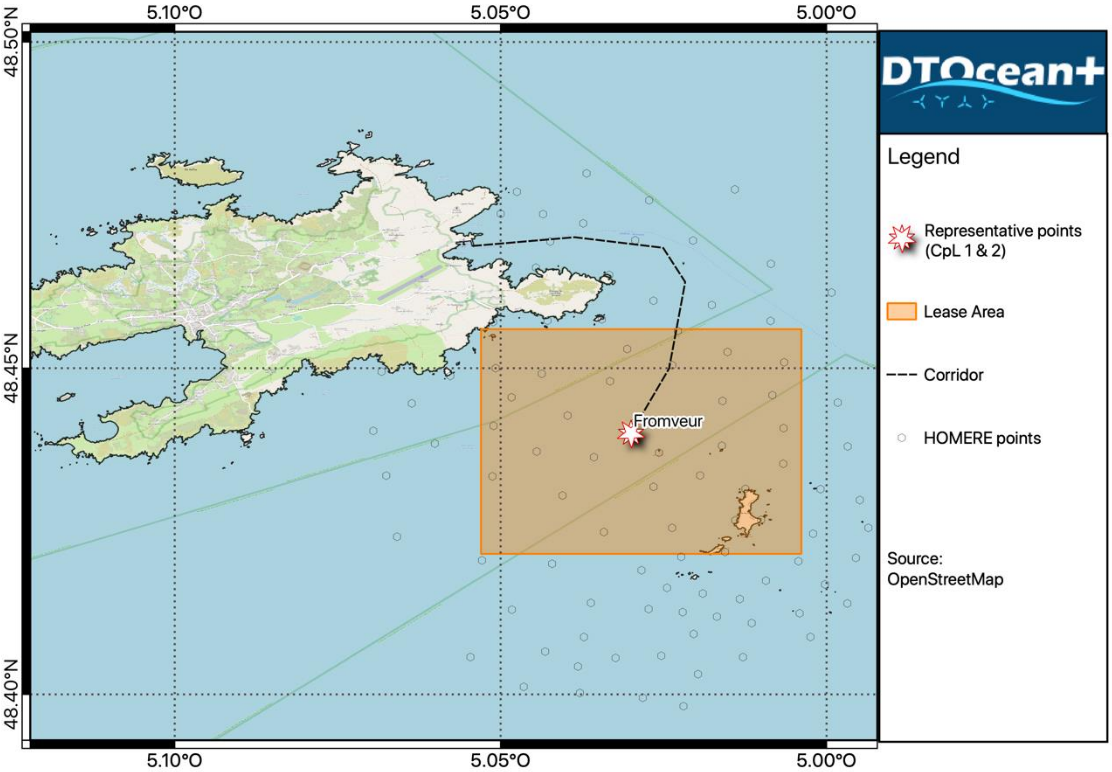


FIGURE 3-6: EXAMPLE OF SITE FOR COMPLEXITY LEVEL 2.

Extraction

The databases that we mentioned previously consist of monthly or annual files in netCDF format.

The SC module will therefore extract these files, whatever their number, by referring to a template defined in a Python dictionary (easily accessible for any code evolution).

In the case of 2D databases, a mesh regrid is performed in order to obtain a regular grid on the right of way of the lease area. The mesh size obtained at the end of this regrid is optimized so as not to degrade the input data.

Timeseries list

Table 3-3 presents the list of timeseries that are extracted from the 2D databases.

TABLE 3-3: LIST OF TIMESERIES EXTRACTED FROM 2D DATABASES.

Waves	
hs (significant wave height)	m
tp (wave peak period)	s
dp (wave peak direction, coming from)	°
te (wave energy period)	s
CgE (wave energy flux)	kW/m
gamma (JONSWAP peak shape parameter)	
spr (wave directional spreading)	°
Currents	
mag (current velocity)	m/s
theta (current direction, going to)	°
U (current zonal velocity)	m/s
V (current meridional velocity)	m/s
Cp (current available power)	W/m2
Wind	
mag10 (10m-wind velocity)	m/s
theta10 (10m-wind direction, coming from)	°
U10 (10m-wind zonal velocity)	m/s
V10 (10m-wind meridional velocity)	m/s
gust10 (10m-wind gusts)	m/s
Water levels	
XE (water surface fluctuation, relative to MSL)	m
WLEV (water level, relative to bottom => XE + bathymetry)	m

3.2.1.3 User databases

For complexity level 3, the user can enter their own files. If he does not have all the necessary input files for the SC module, he will also be able to use the DTOceanPlus databases of the previous 2 levels of complexity.

In order to use his own data, the user must respect certain formats which are described below.

Direct values formats

Direct values databases must be in NetCDF format (https://www.unidata.ucar.edu/software/netcdf/).

Files are a structured matrix whose dimensions are longitude and latitude. Examples can be found in the *Databases* folder of the module.

Possible names for the longitude variable are: 'longitude', 'lon', 'x' or 'X'.

Possible names for the latitude variable are: 'latitude', 'lat', 'y' or 'Y'.

Possible names for the bathymetry variable are: 'H0', 'Band1', 'elevation', 'Bathymetry', 'DEPTH' or 'depth'. Convention is positive values in the ocean, referenced to the mean sea level.

Possible names for the seabed type variable are: 'seabed_type' or 'sediment_type'.

Possible name for the roughness length variable is: 'roughness_length'.

User inputs in terms of endangered species are possible via the ESA tool graphical user interface.

Timeseries formats

Temporal databases must be either in NetCDF format or in CSV format (https://en.wikipedia.org/wiki/Comma-separated_values).

For the NetCDF format, the file must contain all variables and dimensions of the variables are time, longitude, latitude.

For the CSV, the delimiter is the character "," and all the variables must be in the same file.

For 1D timeseries, needed variables are the following (if a variable is missing, fill the column with "0"):

'hs' (significant wave height), 'tom1' (wave energy period), 'spr' (wave directional spreading), 'fp' (wave peak frequency), 'dp' (wave peak direction), 'cge' (wave energy flux), 'wlv' (water level fluctuation), 'ucur' (zonal component of tidal current), 'vcur' (meridional component of tidal current), 'uwnd' (zonal component of 10m-wind), 'vwnd' (meridional component of 10m-wind).

Figure 3-7 shows an example of CSV file that can be used in the SC module (1D timeseries).

	A	B	C	D	E	F	G	H	I	J	K	L
1	times	hs	t0m1	spr	fp	dp	cge	wlv	ucur	vcur	uwnd	vwnd
2	01/01/2019 09:00	5.1	9.7	20.5	0.12	276.2	567.2	0.36	0.68	0.27	10.4	9.3
3	01/01/2019 10:00	5.2	9.2	21.5	0.1	271.3	522.2	0.46	0.58	0.47	8.4	11.3

FIGURE 3-7: EXAMPLE OF CSV FILE FOR 1D TIMESERIES.

For 2D timeseries, needed variables are the following (if a variable is missing, fill the column with "0"):

'hs' (significant wave height), 'fp' (wave peak frequency), 'dp' (wave peak direction), 'wlv' (water level fluctuation), 'ucur' (zonal component of tidal current), 'vcur' (meridional component of tidal current).

Figure 3-8 shows an example of CSV file that can be used in the SC module (2D timeseries), which indicates that all the points (couple of longitude/latitude) must be specified at each time.

	A	B	C	D	E	F	G	H	I
1	times	lon	lat	hs	fp	dp	wlv	ucur	vcur
2	01/01/2019 09:00	4.85	49.12	5.1	0.12	276.2	0.36	0.68	0.27
3	01/01/2019 09:00	4.87	49.14	5.2	0.1	271.3	0.46	0.58	0.47
4	...								
5	01/01/2019 10:00	4.85	49.12	5.0	0.11	274.1	0.39	0.63	0.23
6	01/01/2019 10:00	4.87	49.14	5.2	0.09	271.4	0.45	0.55	0.49

FIGURE 3-8: EXAMPLE OF CSV FILE FOR 2D TIMESERIES.

3.2.2 STATISTICS

3.2.2.1 Statistics definitions

Basic statistics

Basic statistics are computed for every variable extracted from the databases presented in the previous section. Basic statistics include *mean, min, max, median* and *std* values, where:

- The *mean* is the average value of the timeseries, i.e. the sum of individual values over time divided by the number of individual values.
- The *min* and *max* are respectively the lowest and the highest individual values of the timeseries.
- The *median* is a simple measure of central tendency. To find the median, the individual values are arranged in order from smallest to largest value. If there is an odd number of observations, the median is the middle value. If there is an even number of observations, the median is the average of the two middle values.
- The standard deviation *std* is a numerical value used to indicate how widely individuals in a group vary. If individual values vary greatly from the group mean, the standard deviation is big; and vice versa.

Figure 3-9 is provided to the user in order to have an overview of the basic statistics on a site.

Variable	Min	Mean	Max	Std
Waves **Hs [m]**	0.17	1.37	9.4	0.83
Currents **Mag [m/s]**	0.04	1.71	3.96	0.96
Winds **Mag10 [m/s]**	0.1	7.47	27.29	3.63
Water levels **WLEV [m from MSL]**	52.97	56.39	59.81	1.66

FIGURE 3-9: OVERVIEW OF BASIC STATISTICS ON A GIVEN SITE.

EPD

EPD (Empirical Probability Distribution) represents the distribution of the variable, directly extracted from the database. It shows the percentage of occurrence of the variable inside a range of bins.

In SC module, this statistic is also available broken down by months.

Figure 3-10 shows an example of an EPD statistic on Hs (significant wave height).

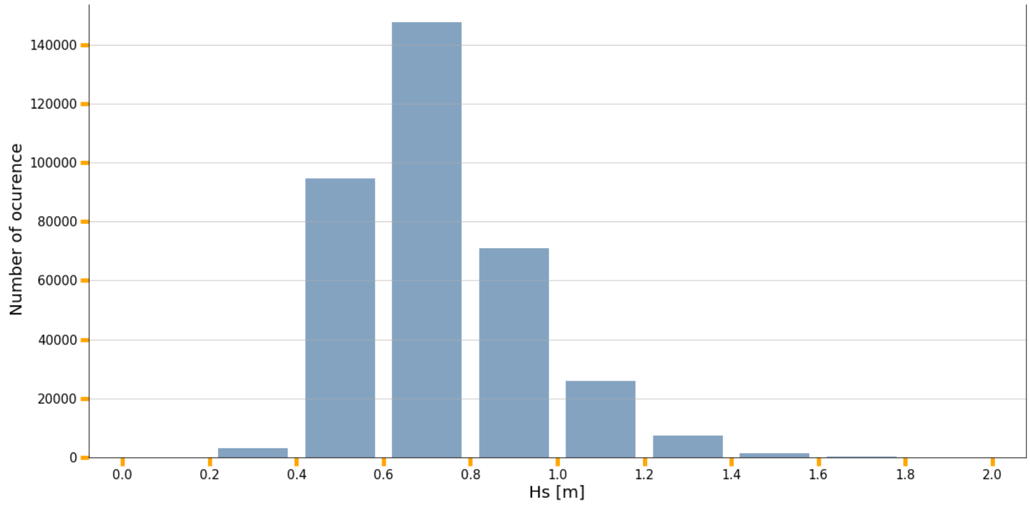


FIGURE 3-10: EMPIRICAL PROBABILITY DISTRIBUTION OF HS AT A GIVEN SITE.

EJPD

EJPD (Empirical Joint Probability Distribution) represents the distribution of two variables, considered together. It shows the percentage of occurrence inside bins.

In SC module, this statistic is also available broken down by months.

Figure 3-11 shows an example, provided to the user, of an EJPD statistic on Hs (significant wave height) and Tp (wave peak period).

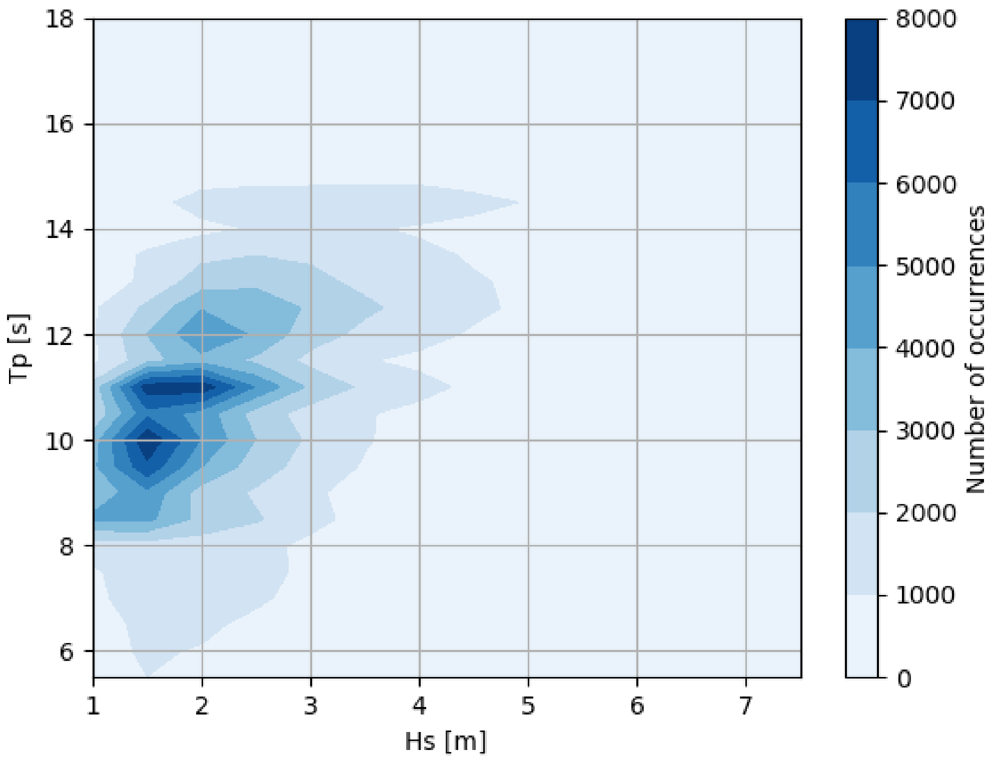


FIGURE 3-11: EMPIRICAL JOINT PROBABILITY DISTRIBUTION OF HS AT A GIVEN SITE.

ENVS

This statistic computes the wave environments Hs/Dp in order to calculate the fatigue analysis in the module Station Keeping of the DTOcean+ suite. It uses the statistic EJPD to jointly cut Hs and Tp by bins and then classifies the results from the most probable environment to the less probable one. It also associates to each of these environments the mean wave peak period (Tp), the maximum current speed and its associated current direction, the maximum wind speed and its associated wind direction. More information is available in "D6.2 Station Keeping Tools".

EXT

EXT (EXTreme) statistic is based on an Extreme values analysis. It uses probabilistic laws to predict extreme events (also called extreme values, or return values) for a particular phenomenon, over large return periods that usually exceed the duration of the measured or modelled data.

There are two definitions of an extreme event, given by the two theorems of the extreme value theory.

• The Fisher-Tippett-Gnedenko theorem (known as the first theorem of the extreme value theory) states that the distribution of block maxima can be accurately described by a Generalized Extreme Values distribution (GEV).

• The Pickands-Balkema-de Haan theorem (known as the second theorem of the extreme value theory) states that the distribution of peaks over a threshold (POT) can be accurately described by a Generalized Pareto distribution (GPD).

In the SC module, GEV is used to compute the extreme values of tidal currents and the GPD is used to compute the extreme values of waves and winds.

Figure 3-12 is provided to the user in order to have an overview of the extreme values for each parameter on a site.

Variable / RP	1y	5y	10y	50y
Waves Hs [m]	6.22	8.68	11.04	12.26
Currents Mag [m/s]	NotAvailable	3.96	3.97	3.97
Winds Mag10 [m/s]	23.79	27.29	28.67	29.19

FIGURE 3-12: OVERVIEW OF EXTREME CONDITIONS AT A GIVEN SITE.

EXC

EXC (Extreme Contours) is the statistics *extreme* contours, also known as environmental contour, this statistic represents a rational procedure for defining an extreme sea stat condition. The objective is to define contours in the environmental parameter space along which extreme responses with given return period should lie (Winterstein et al., 1993) (DNV-RP-C205, 3.7.2).

The extreme contours represent extreme conditions for the governing variable (in SC module, the significant wave height) and the expected associated value of a second variable (in SC module, the wave peak period). In SC module, extreme contours are computed following the IFORM approach (Figure 3-13).

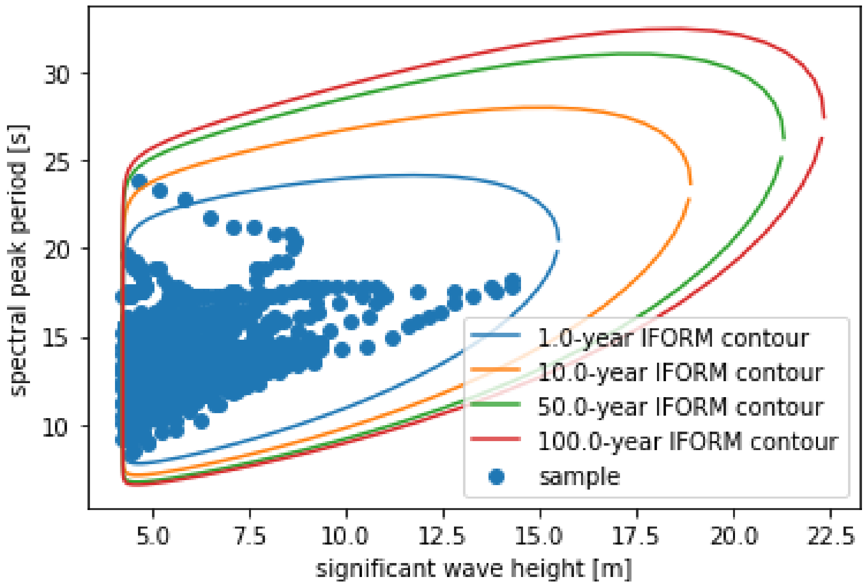


FIGURE 3-13: EXTREME CONTOURS OF HS AND TP AT A GIVEN SITE.

3.2.2.2 Statistics list

Table 3-4 presents all the statistics that are computed in the SC module.

TABLE 3-4: LIST OF STATISTICS COMPUTED IN SC MODULE.

Waves	
hs basics (mean, min, max, median, std)	m
tp basics (mean, min, max, median, std)	s
CgE basics (mean, min, max, median, std)	kW/m
gamma basics (mean, min, max, median, std)	
spr basics (mean, min, max, median, std)	°
EPD hs (Empirical Probability Distribution)	occurrences
monthly-EPD hs (Empirical Probability Distribution)	occurrences
EPD dp (Empirical Probability Distribution)	occurrences
monthly-EPD dp (Empirical Probability Distribution)	occurrences
EPD tp (Empirical Probability Distribution)	occurrences
monthly-EPD tp (Empirical Probability Distribution)	occurrences
EJPD hs/tp (Empirical Joint Probability Distribution)	occurrences
monthly-EJPD hs/tp (Empirical Joint Probability Distribution)	occurrences
EJPD hs/dp (Empirical Joint Probability Distribution)	occurrences
monthly-EJPD hs/dp (Empirical Joint Probability Distribution)	occurrences
EJPD3v hs/dp/tp (Empirical Joint Probability Distribution with 3 variables)	occurrences
EXT hs (extreme return values)	m
EXT tp (extreme return values)	s
EXC hs/tp (multivariate extreme return values or contours)	m ; s
Currents	
mag basics (mean, min, max, median, std)	m/s
Flux basics (mean, min, max, median, std)	W/m2
Flux std	W/m2
EPD mag (Empirical Probability Distribution)	occurrences
monthly-EPD mag (Empirical Probability Distribution)	occurrences
EPD theta (Empirical Probability Distribution)	occurrences
monthly-EPD theta (Empirical Probability Distribution)	occurrences
EJPD mag/theta (Empirical Joint Probability Distribution)	occurrences
monthly-EJPD mag/theta (Empirical Joint Probability Distribution)	occurrences
EXT mag (extreme return values)	m/s
Wind	
mag10 basics (mean, min, max, median, std)	m/s
EPD mag10 (Empirical Probability Distribution)	occurrences

monthly-EPD mag10 (Empirical Probability Distribution)	occurrences
EPD theta10 (Empirical Probability Distribution)	occurrences
monthly-EPD theta10 (Empirical Probability Distribution)	occurrences
EJPD mag10/theta10 (Empirical Joint Probability Distribution)	occurrences
monthly-EJPD mag10/theta10 (Empirical Joint Probability Distribution)	occurrences
EXT mag10 (extreme return values)	m/s
EXT gust10 (extreme return values)	m/s
Water levels	
WLEV basics (mean, min, max, median, std)	m
EPD WLEV (Empirical Probability Distribution)	occurrences
monthly-EPD WLEV (Empirical Probability Distribution)	occurrences
EXT WLEVnegative (extreme return values)	m
EXT WLEVpositive (extreme return values)	m

4. THE IMPLEMENTATION

4.1 THE ARCHITECTURE OF THE TOOL

The DTOceanPlus tools have been implemented considering three layers:

- The Business Logic, including a set of modules, classes, libraries implementing all the functionalities of the modules.
- The Application Programming Interface (API) that constitutes the gate of the module to the other modules that consume the services provided by SC.
- The Graphic User Interface (GUI), allowing interaction with the user in order to show results and receive inputs, besides exporting/importing data to/from files.

4.1.1 BUSINESS LOGIC

The architecture of the Business Logic of SC reflects, also in its architecture, the functionalities that were described in Section 2.

Five main classes, indeed, have been considered to cover all the functionalities:

- MyProject (Project.py)
- MySite (Site.py)
- MyData (Data.py)
- MyPoint/MyPoints (Location.py)
- MyStatistics (Statistics.py)

These classes and their methods are presented in Figure 4-1.

4.1.1.1 Project.py

The Project module is the module that is used to launch all the process; it uses the class MySite for extractions and computations after reading the GUI via API.

This module uses the API results to initialise objects that will be used by MySite.

This module also launches the plotting section in order to produce figures for the user, which are then accessible via the GUI.

The methods of this module are listed below:

- *__init__()* : will initialize MyProject attributes (name, level, ..).
- *__load_shapefiles__()* : will load shapefiles (ESRI format, « .shp ») of the lease area and corridor of the farm.
- *__launch_extractions__()* : will launch the 1D databases extractions by calling the classe MySite.
- *__extract_2D_values__()* : will launch the 2D databases extractions by calling the classe MySite.
- *__launch_statistics__()* : will launch all the statistics on extracted variables.

- *__plot_results__()* : will plot some results of the project in order to have an overview of the site conditions.
- *__store_project__()* : will save the project as a json file in the storage folder.

4.1.1.2 Site.py

The Site module is the module that is used to launch all the computations. This module uses several configuration files to initialise objects that will be used by other modules to compute extractions and statistics. The methods of this module are listed below:

- *__init__()* : will initialize MySite attributes (databases names, storage folder, ..).
- *__extract_single_values_at_points__():* will extract direct values from databases by calling the class MyData.
- *__compute_slope__():* will compute the local slope of the bottom by calling the class MyData.
- *__extract_time_series_at_points__():* will launch an extraction of 1 variable from the 1D temporal databases by calling the classe MyData.
- *__extract_several_time_series_at_points__():* will launch an extraction of several variables from the 1D temporal databases by calling the classe MyData.
- *__extract_several_2D_variables__():* will launch an extraction of several variables from the 2D temporal databases by calling the classe MyData.
- *__launch_stats__()* : will launch the punctual statistics computation by calling the script Statistics.py.
- *__launch_2D_stats__()* : will directly compute the 2D statistics.

4.1.1.3 Data.py

This module defines the Data class that is used to extract Physical Databases. It reads the catalogue of databases to find requested files and launch the extractions via the classes MyPoint (1D) and MyPoints (2D). The methods of this module are listed below:

- *__init__()* : will initialize MyData attributes (name, catalog, driver, extent, ..).
- *__find_data_in_catalog__()* : will find the requested database in the catalog.
- *__extract_single_value__()* : will extract direct values from the requested database by calling the class MyPoint.
- *__compute_my_slope__():* will compute the local slope of the bottom by calling the class MyPoint.
- *__extract_time_series__()* : will launch an extraction of 1 variable from the requested 1D temporal database by calling the classe MyPoint.
- *__extract_several_time_series__()* : will launch an extraction of several variables from the requested 1D temporal database by calling the classe MyPoint.
- *__intersection_with_polygon__()* : will compute the list of the requested database points that are in the lease area.
- *__extract_2D_variables__()* : will launch an extraction of several variables from the 2D temporal databases by calling the classe MyPoints for the points which are in the lease area.

4.1.1.4 Locations.py

This module provides objects that handle the locations of the Site. It is composed of two main classes, MyPoint and MyPoints, which are respectively dedicated to 1D databases and 2D databases. The methods of the class MyPoint are listed below:

- *__init__() :* will initialize MyPoint attributes (name, longitude and latitude).
- *get_value() :* will extract a direct value from a database.
- *get_local_slope()* : will compute the local bottom slope.
- *find_files()* : will iterate over the file of a database.
- *_get_time_series_length()* : will compute the length of the temporal dimension in order to instantiate the different vectors.
- *get_time_series()* : will extract a variable from a 1D temporal database.
- *get_time_series_several_variables():* will extract several variables from a 1D temporal database.

The methods of the class MyPoints are listed below:

- *__init__()* : will initialize MyPoints attributes (names, longitudes and latitudes).
- *find_files()* : will iterate over the file of a database.
- *_get_time_series_length()* : will compute the length of the temporal dimension in order to instantiate the different vectors.
- *get_time_series_several_variables():* will extract several variables from a 2D temporal database.

4.1.1.5 Statistics.py

This module defines the class Statistics that is used to build the specific instances and to compute all the statistics over the variables extracted from the databases. The functions available in Statistics.py are listed below:

- basic_stats() : will compute basic statistics: min, mean, median, max, std
- EPD() : will compute empirical probability distribution.
- EJPD() : will compute empirical joint probability distribution.
- largest_indices() : will return the n largest indices from an array.
- Environments_SK() : will compute environments for fatigue analysis (for Station Keeping module).
- EJPD3v() : will compute empirical joint probability distribution of 3 variables (here Hs, Tp and Dp).
- EXT() : will compute the extreme value analysis of 1 variable.
- find_peaks() : will find the peaks over a threshold for extreme value analyses.
- EXC() : will compute the extreme contours of 2 variables.

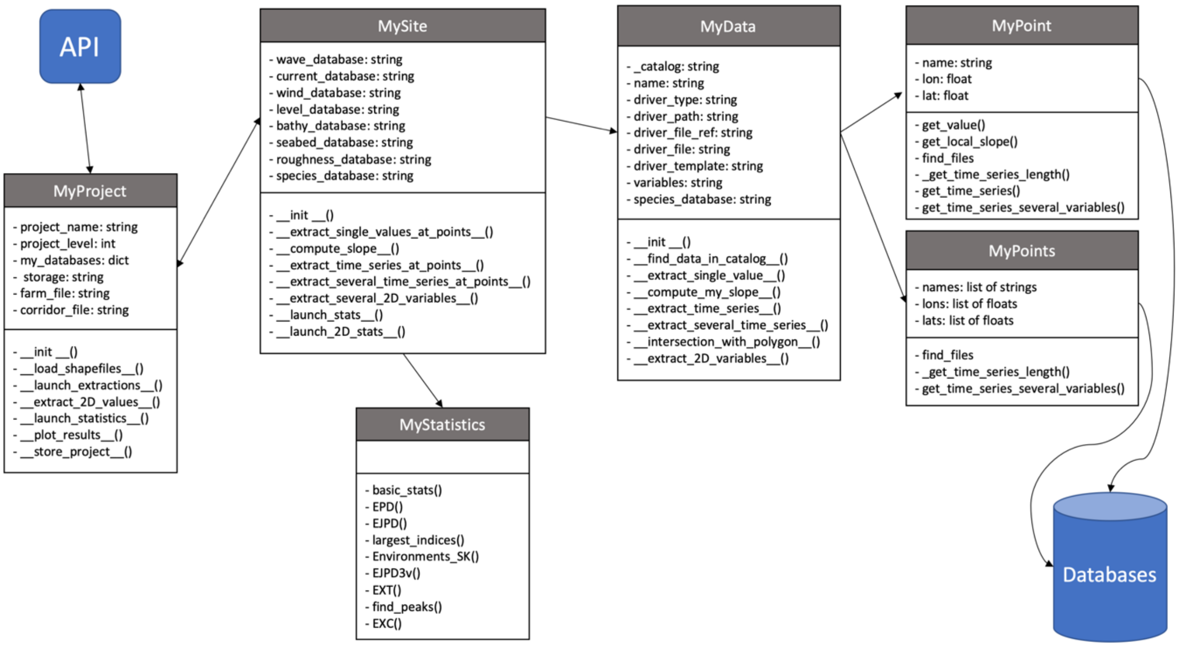


FIGURE 4-1: CLASS DIAGRAM OF THE SC MODULE BUSINESS LOGIC.

4.1.2 API

The API of the DTOceanPlus software follows a representational state transfer (REST) approach and it uses HTTP as the transport protocol. Its robustness is due to strict design principles whose development it has been based on.

The SC API follows those principles and the language OpenAPI is adopted. An OpenAPI file was created, in json format, indicating all the paths, the services, and schemas that SC will consume, and which will be made for other modules to be consumed.

The backend of the module receives the services from the other modules, running the Business Logic and then preparing the outputs for the other modules and the users. This has been coded in Python, using Flask Blueprints.

This API is called by the frontend of the software, the GUI, described in the next section.

4.1.3 GUI

The GUI of all modules of DTOceanPlus will be all based on the same libraries to guarantee a consistent visual look. The GUI of the SC module will be included into the main module. On the home page of the SC module, the user will have the choice to either create a new site or to access the list of previous project's site (Figure 4-2).

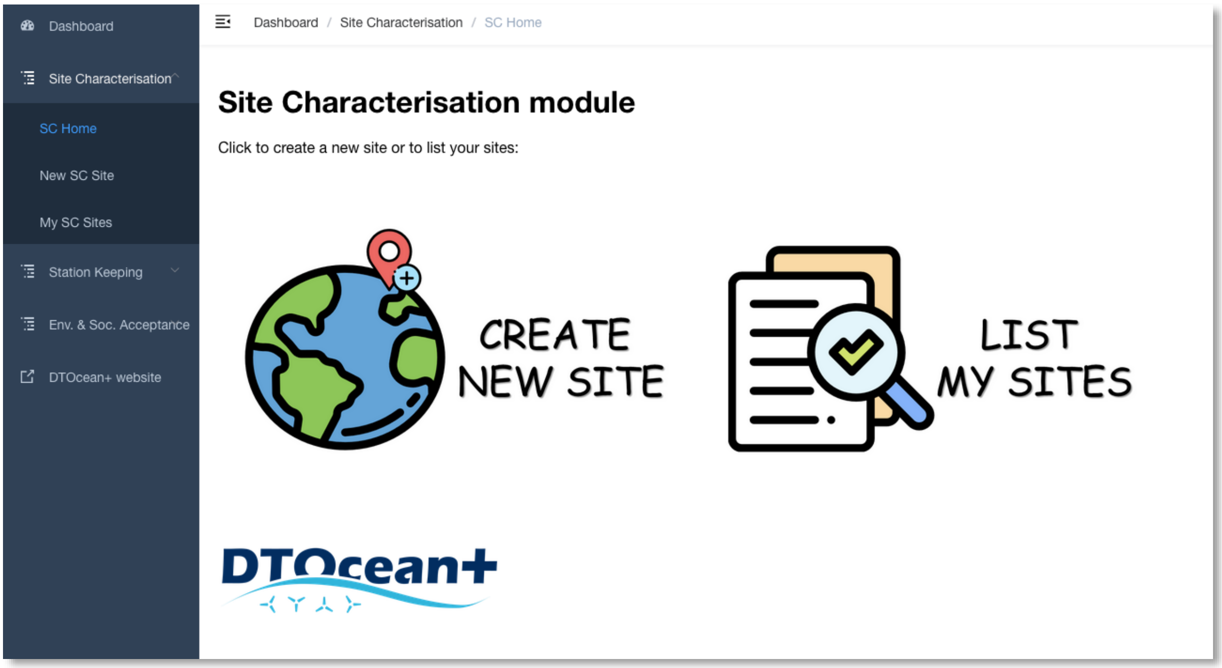


FIGURE 4-2: WIREFRAME OF THE GUI OF THE SC MODULE: HOME PAGE.

If the user chooses to create a new site, they will be redirected to the site creation page (Figure 4-3). On this page they have to choose a name for his project and a level of complexity (Figure 4-3 shows the interface for complexity levels 1 and 2; the interface for level 3 is under development). Depending on the requested level of complexity, the user will have to either choose the levels of energy of the site or to download his own databases.

When it is done, they can launch the site creation by clicking on the green button. It will launch the extractions and the statistics computations described in the previous sections.

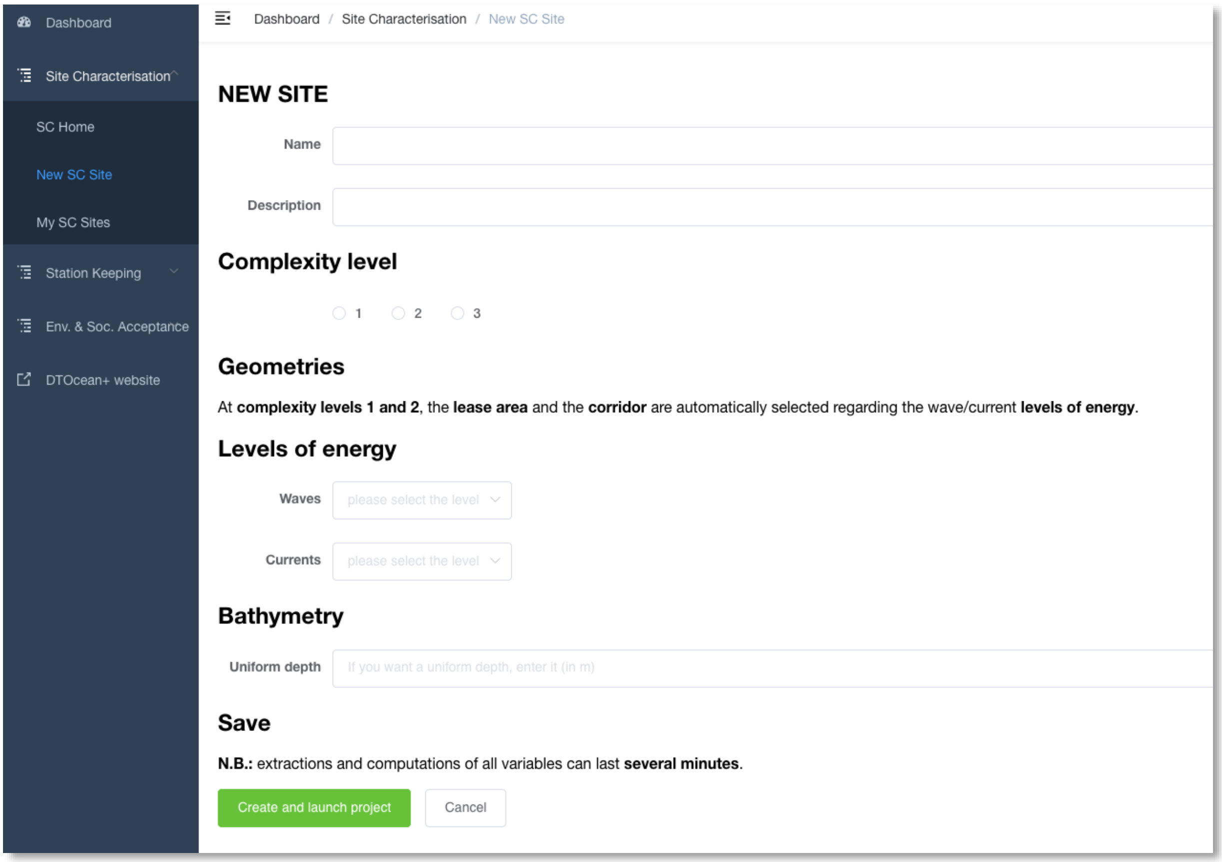


FIGURE 4-3: WIREFRAME OF THE GUI OF THE SC MODULE: NEW SITE PAGE.

When 1 or several sites have been created, the user can list them by clicking on "My SC sites" on the left panel, or on "List my sites" on the homepage (Figure 4-2).

They will be redirected on the listing page (Figure 4-4), where they have access to the name of the existing sites, their dates of creation and a button to see each site results.

By clicking on the button "View Site results", the user will have access to the main tables and graphs which have been created after the statistics computation, in order to have an overview of the site conditions (Figure 4-5).

In the case of 2D databases (complexity levels 2 and 3), the user can also access to 2D map (Figure 4-6).

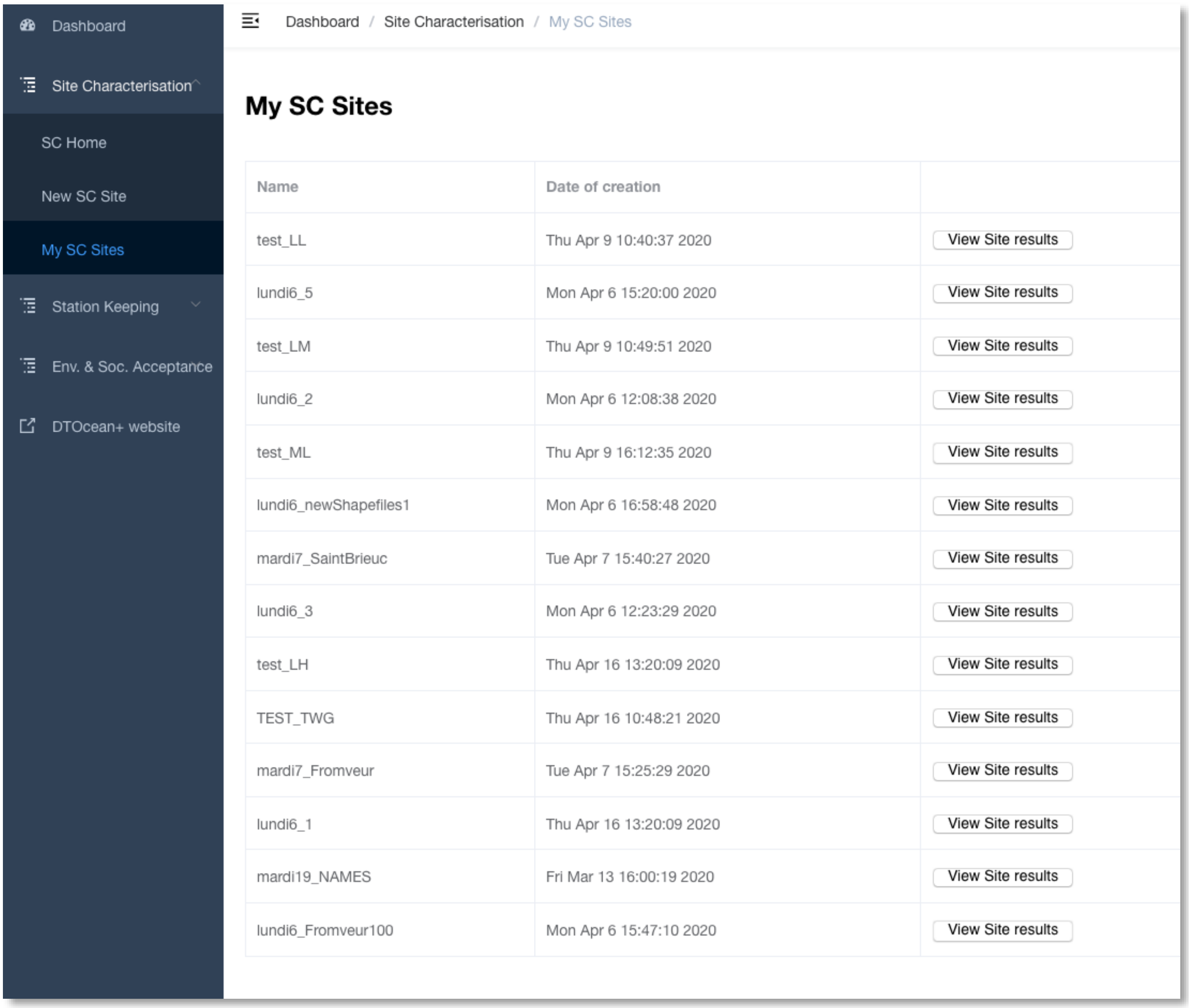


FIGURE 4-4: WIREFRAME OF THE GUI OF THE SC MODULE: SITES LISTING PAGE.

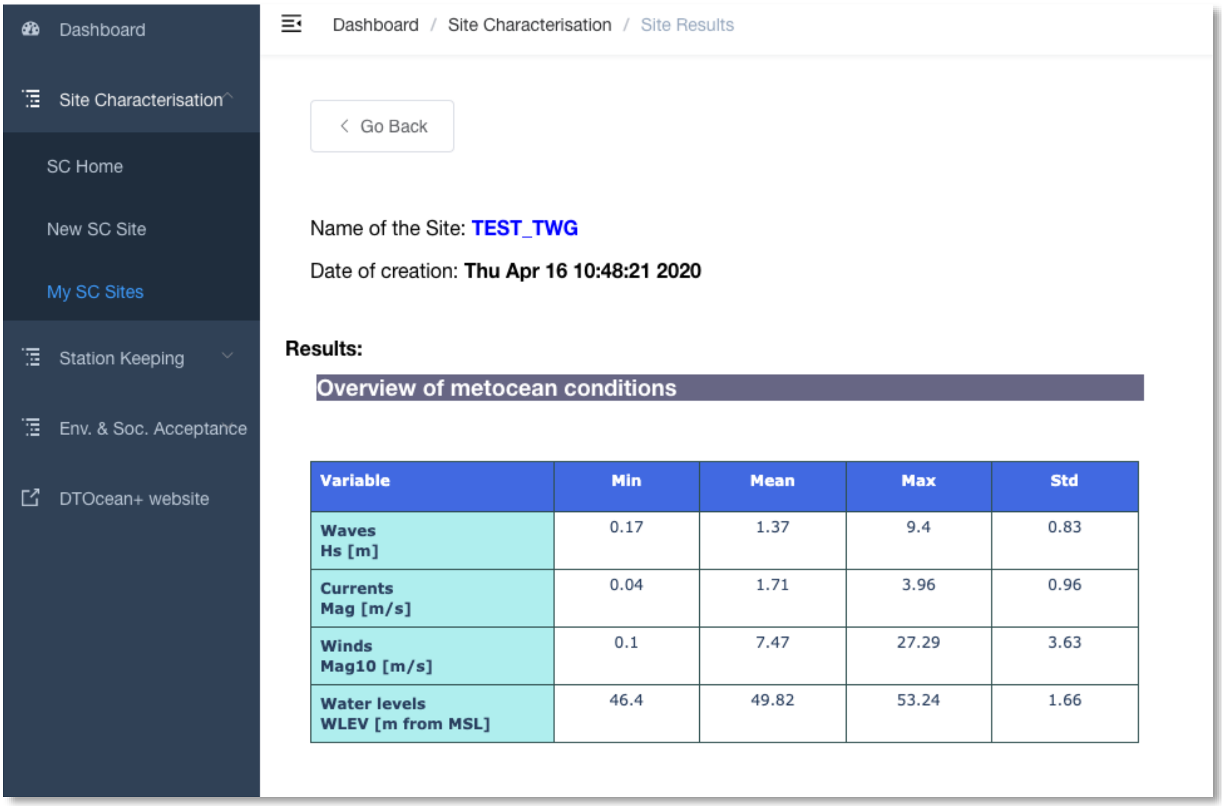


FIGURE 4-5: WIREFRAME OF THE GUI OF THE SC MODULE: SITE RESULTS PAGE.

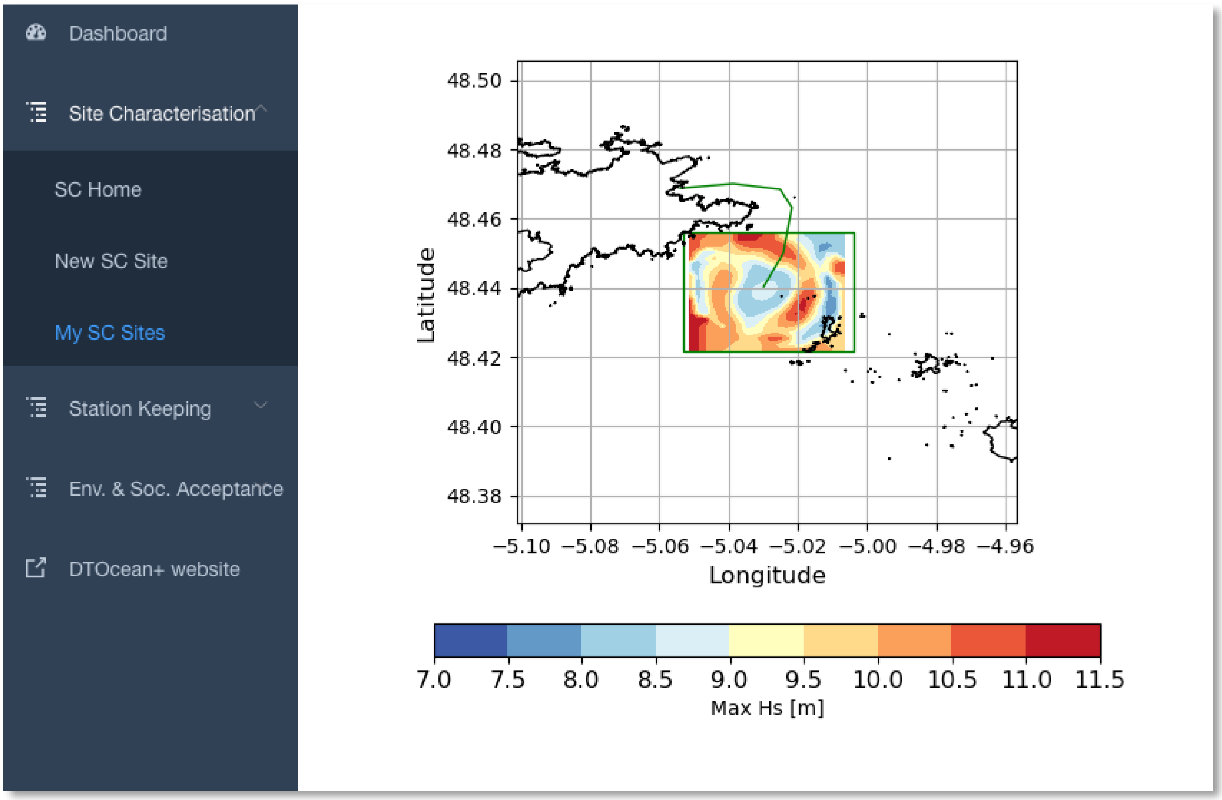


FIGURE 4-6: WIREFRAME OF THE GUI OF THE SC MODULE: SITE RESULTS PAGE FOR 2D DATABASES.

The GUI is still under development during the integration phase of the DTOceanPlus software. The wireframes above (Figure 4-2, Figure 4-3, Figure 4-4, Figure 4-5 and Figure 4-6) present the main functionality that the GUI of SC have, but the final implementation is subject to change.

4.1.4 THE TECHNOLOGIES

The Business Logic and the API of SC have been coded in Python version 3.6. The installation of the module requires the following packages:

- NumPy
- netCDF4
- Matplotlib
- geopandas
- Flask
- flask-babel
- flask-cors
- lmoments3
- peakutils
- viroconcom
- pandas.

The API relies on OpenAPI specification v3.0.2. The GUI of the module is developed in Vue.js, using the library Element-UI.

4.2 TESTING AND VERIFICATION

The Business Logic implemented a validation of the data inputs, checking whether the required inputs for each method are set to "None" values. Similarly, in the Business Logic it has been taken into account a situation where some values are zero, leading to numerical errors because of the division by zero.

In total, a set of 2130 statements are present in the Business logic. A comprehensive set of "unit test" (29 unit tests of the Business Logic only) has been implemented covering the different functionalities of the Business Logic, and the coverage of these tests, measured by means of the py-cov extension of the py-test library, is 91 % of the Business Logic (see Figure 4-7).

Module ↓	*statements*	*missing*	*excluded*	*branches*	*partial*	*coverage*
src/dtop_site/BusinessLogic/Data.py	97	1	0	12	2	97%
src/dtop_site/BusinessLogic/Location.py	361	22	0	86	4	91%
src/dtop_site/BusinessLogic/Project.py	599	39	0	64	8	93%
src/dtop_site/BusinessLogic/Read.py	46	1	0	22	1	97%
src/dtop_site/BusinessLogic/Site.py	616	48	0	112	17	87%
src/dtop_site/BusinessLogic/catalogs/data_catalog.py	15	0	0	0	0	100%
src/dtop_site/BusinessLogic/catalogs/early_stage_energy_databases.py	3	0	0	0	0	100%
src/dtop_site/BusinessLogic/plot_functions.py	109	4	0	28	10	90%
src/dtop_site/BusinessLogic/statistics.py	165	12	0	38	7	90%
src/dtop_site/BusinessLogic/useful_functions.py	119	8	0	28	5	88%
Total	**2130**	**135**	**0**	**390**	**54**	**91%**

coverage.py v5.1, created at 2020-04-30 16:29

FIGURE 4-7: COVERAGE OF THE TESTING ON THE BUSINESS LOGIC BY MEANS OF UNIT TESTS.

The unit test coverage of the Business Logic of SC is very high, ensuring quality of the code and guaranteeing that future developments on the same module won't break the current functionalities.

5. EXAMPLES

In this section, an example for each type of temporal extraction (for 1D or 2D databases) has been carried out and the outputs are presented as they will be integrated in the DTOceanPlus suite of tools when released.

5.1 PUNCTUAL DATA

The punctual data case is represented by level of complexity 1 (it can also be encountered in level of complexity 3, if the user provides a 1D time database).

The user creates a new site by going to the creation page (see section 4.1.3). They enter the name of his site as well as a description of the site if he wishes. He then selects level of complexity "1" (see Figure 5-1) as well as the energy levels representative of his site for waves and tidal currents.

If they prefer constant bathymetry rather than the actual bathymetry, they can also specify it.

They then launch the creation of the site by clicking on the green button "Create and launch project" at the bottom of the page.

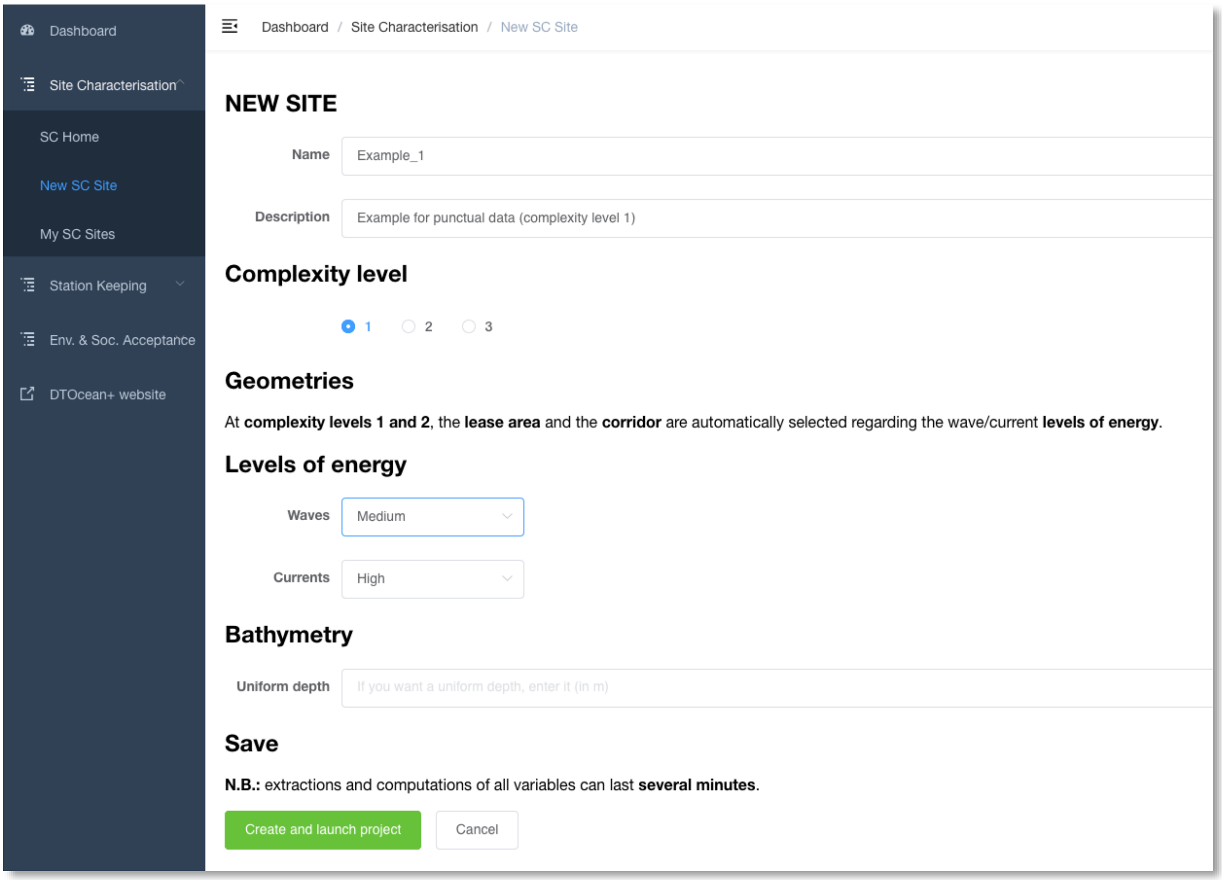
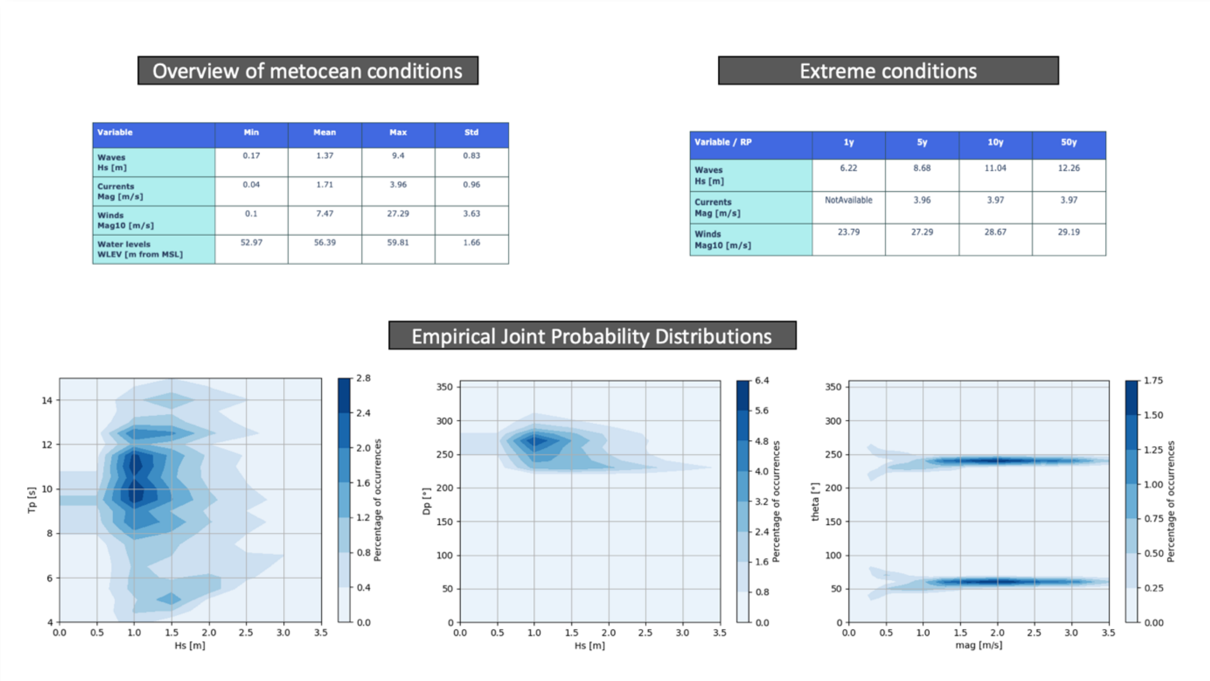


FIGURE 5-1: CREATION PAGE FOR COMPLEXITY LEVEL 1.

This action lasts a few minutes because all the necessary files needs to be extracted and the statistics will have to be calculated.

The user then has access to the results via the listing page sites (see section 4.1.3):

- overview of metocean conditions gives basic statistics for waves, currents, winds and water depths;
- the extreme conditions: gives the extreme return values for waves, currents, winds and heights of water;
- EJPD: Hs/Tp and Hs/Dp for waves and mag / theta for currents (see Figure 5-2).



Overview of metocean conditions

Variable	Min	Mean	Max	Std
Waves Hs [m]	0.17	1.37	9.4	0.83
Currents Mag [m/s]	0.04	1.71	3.96	0.96
Winds Mag10 [m/s]	0.1	7.47	27.29	3.63
Water levels WLEV [m from MSL]	52.97	56.39	59.81	1.66

Extreme conditions

Variable / RP	1y	5y	10y	50y
Waves Hs [m]	6.22	8.68	11.04	12.26
Currents Mag [m/s]	NotAvailable	3.96	3.97	3.97
Winds Mag10 [m/s]	23.79	27.29	28.67	29.19

FIGURE 5-2: RESULTS (1D STATISTICS).

5.2 2D SPATIAL DATA

The 2D spatial data case is represented by level of complexity 2 (it can also be encountered in level of complexity 3, if the user provides a 2D time database).

The user creates a new site by going to the creation page (see section 4.1.3). They enter the name of his site as well as a description of the site if they wish. They then select level of complexity "2" (see Figure 5-3) as well as the energy levels representative of their site for waves and tidal currents.

If they prefer a constant bathymetry rather than the actual bathymetry, they can also specify it.

They then launch the creation of the site by clicking on the green button "Create and launch project" at the bottom of the page.

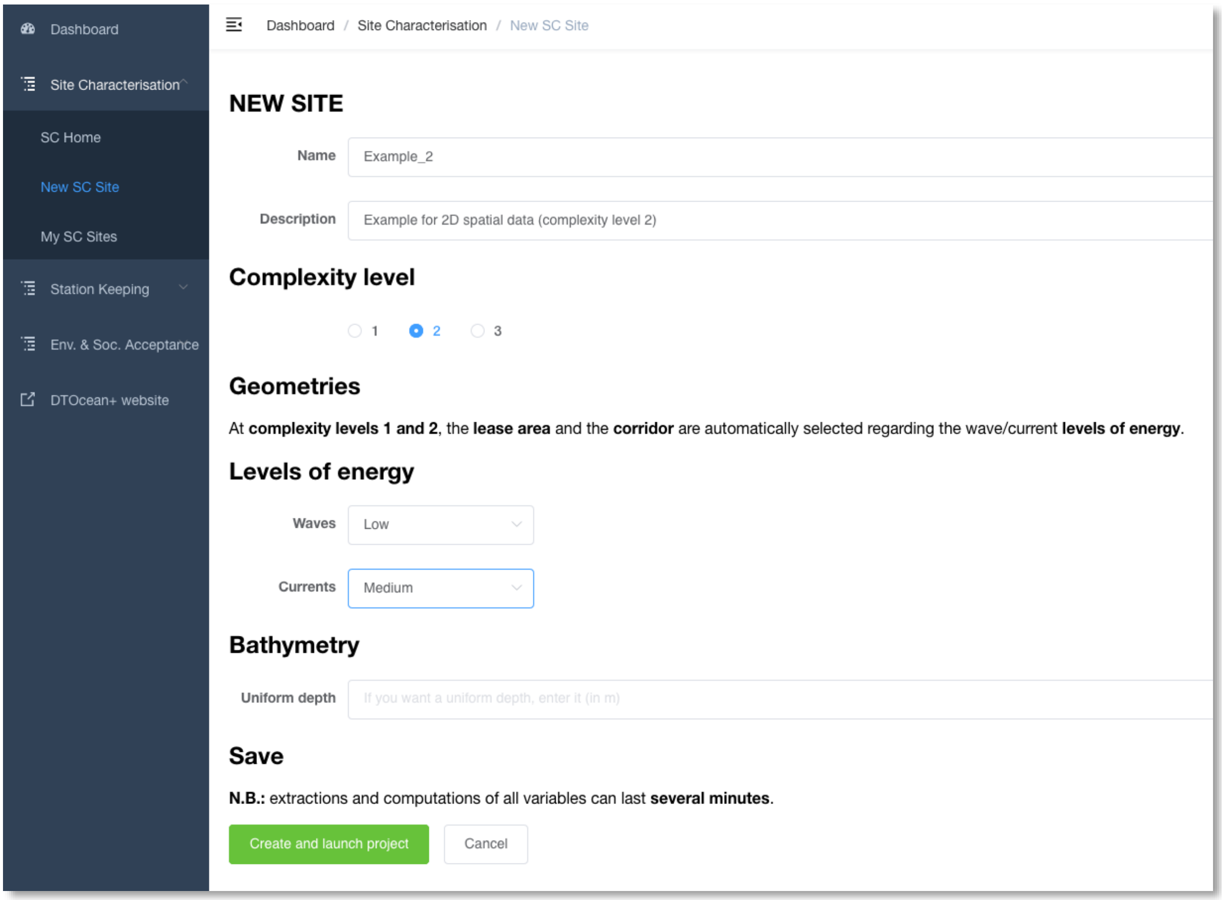
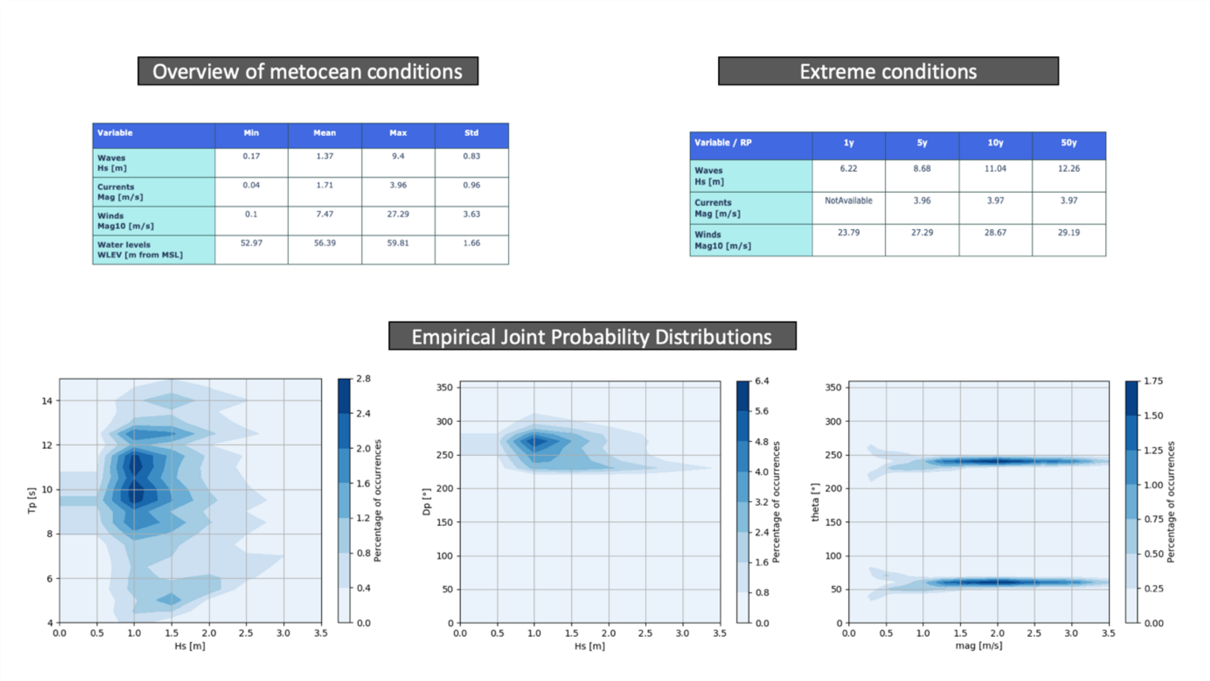


FIGURE 5-3: CREATION PAGE FOR COMPLEXITY LEVEL 2.

This action lasts a few minutes because all the necessary files needs to be extracted and the statistics will have to be calculated.

The user then has access to the results via the listing page sites (see section 4.1.3):

- overview of metocean conditions gives basic statistics for waves, currents, winds and water depths;
- the extreme conditions: gives the extreme return values for waves, currents, winds and heights of water;
- EJPD: Hs/Tp and Hs/Dp for waves and mag / theta for currents (Figure 5-4).
- Maps of mean and maximum tidal current magnitude,
- Maps of mean and maximum significant wave height (Figure 5-5).



Overview of metocean conditions

Variable	Min	Mean	Max	Std
Waves Hs [m]	0.17	1.37	9.4	0.83
Currents Mag [m/s]	0.04	1.71	3.96	0.96
Winds Mag10 [m/s]	0.1	7.47	27.29	3.63
Water levels WLEV [m from MSL]	52.97	56.39	59.81	1.66

Extreme conditions

Variable / RP	1y	5y	10y	50y
Waves Hs [m]	6.22	8.68	11.04	12.26
Currents Mag [m/s]	NotAvailable	3.96	3.97	3.97
Winds Mag10 [m/s]	23.79	27.29	28.67	29.19

FIGURE 5-4: RESULTS (1D STATISTICS).

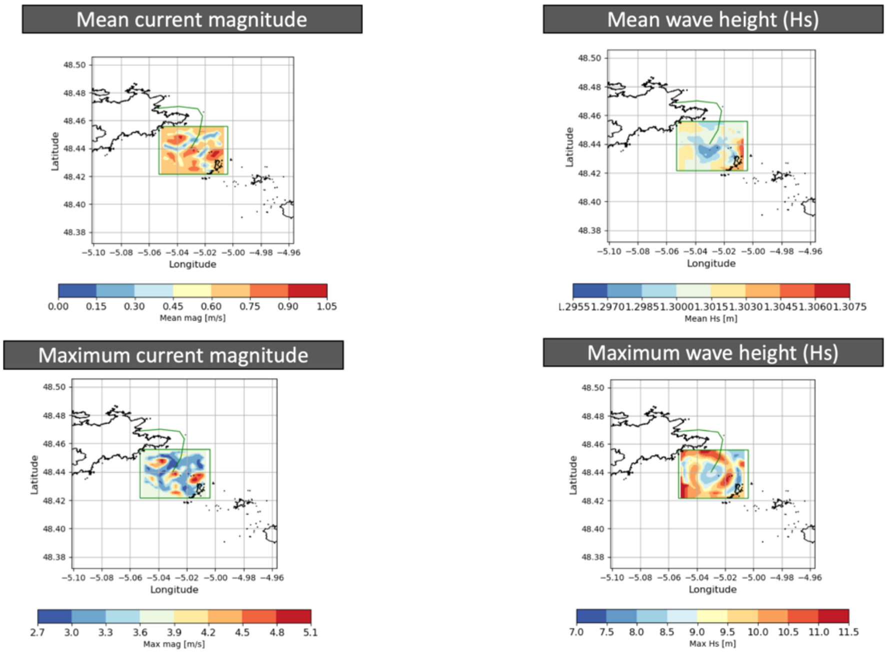


FIGURE 5-5: RESULTS (2D MAPS).

6. FUTURE WORK

This deliverable collects the main functional and technical aspects of the Site Characterisation module (SC), implemented during the tasks T5.1 and T5.3 of the DTOceanPlus project.

While the module can be run in a standalone mode at the moment of writing, some work is required yet to be fully integrated in the suite of tools of DTOceanPlus:

- The OpenAPI file should be "linked" to the other module's equivalent files, in order to guarantee a smooth, robust and consistent data flow among the different pieces of the tool;
- The API should be further developed in order, again, to integrate the module with the other tools;
- The GUI will be developed to be consistent with the other tools and to provide the user with an easy access to the tool and its functionalities.

Future work should also include the integration of the results from the ResourceCode project (new created database) and to directly link these results with SC module through a specific API.

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