FORESHORE ASSESSMENT USING SPACE TECHNOLOGY

Release of regionalised MI-SAFE functional prototype for case study sites

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Authors	Gerrit Hendriksen (Deltares) Joan Sala Calero (Deltares) Jasper Dijkstra (Deltares) Gloria Peralta (UCA) Daphne van der Wal (NIOZ) Iris Möller (UCam)
Contributors	Myra van der Meulen (Deltares) Mindert de Vries (Deltares)
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Content

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Executive summary / Abstract

The objective of the FAST project is to develop Copernicus downstream services. The role of work package 5 (WP5) is to develop the MI-SAFE package, as well as developing the business case and the interaction with end users. The project has implemented several products and services, including an online viewer 'MI-SAFE' , a wealth of downloadable data layers, Open Software modelling and more Advanced services (training and consultancy). Together, we call this the 'MI-SAFE package'. Here, Sentinel satellite data and in situ data (from eight different foreshore case study areas in four different countries) are combined to help clarify the protective role of wetlands in flood risk management strategies.

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Scope

The EU Foreshore Assessment using Space Technology (FAST) focuses on the assessment of foreshores, including vegetation and stability variables, using satellite imagery, to be used in a foreshore assessment package, named MI-SAFE. This report, Deliverable 5.12 (D5.12), describes the structures and functionalities of the MI-SAFE viewer specifically, but also discusses the added value of this product for end user and how it is applied to real cases from the field (study sites) and to all coasts of the world.

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1 Introduction

1.1 Background

The FAST project focuses on temporarily submerged and vegetated areas in front of levees and seawalls and on the valuable protective services these areas can offer. The project is driven by the need to improve human and infrastructure safety through making use of these services. Adaptive management of foreshores and floodplains to reduce flooding can (1) reduce flood defence infrastructure costs, and (2) balance the many values of ecosystems, including their protective functions, and socioeconomic uses. FAST has developed the MI-SAFE package, and more specifically the MI-SAFE viewer (on-line software product), to allow the methodological exploration of foreshore and floodplain characteristics and their effect on waves and flood water depth / flood current speeds and thus their impact on protective levees commonly deployed as flood and erosion protection features across European countries and beyond. MI-SAFE uses space-borne, air-borne, and field data to classify foreshore and floodplain characteristics and establish linkages between parameters determined at a variety of spatial scales. FAST has been ensuring end-user commitment and involvement in a user-driven approach to product design and implementation, relying on inter-active consultation and regional discussions with end users. During a series of science meetings, the algorithms linking Earth Imagery with the numerical modelling where identified and specified. Geospatial analysis and visualisations are an important part of the MI-SAFE viewer. The geospatial analysis tools consist of existing open source software with newly developed tools progressing beyond the state of the art in terms of the mapping of foreshore features and coupling it directly to modelling results.

In the Description of Work (DoW), the MI-SAFE viewer was defined to enable users to:

- Translate effects of foreshores and floodplains on waves/flow and stability into impacts on engineering requirements for flood safety infrastructure;
- Automate linkages between biological and morphological features of foreshores/floodplains and requirements for flood safety infrastructure.

As part of the business case discussion with end users around the MI-SAFE viewer, it was decided that, the most important determinant for the development of the viewer was the type of end-user (Public, NGO, Private, etc.), rather than the specific coast to which the viewer is applied. Therefore, in this deliverable, the regionalisation of the MI-SAFE viewer is not included. The different modes of the MI-SAFE viewer are regionalized through the case study areas in the Expert mode and the Educational version that has a global coverage.

1.2 Rationale

The MI-SAFE package has been developed following open source principles by using the Open Earth software tools available at Deltares. In this way the development complied with European software strategy as formulated in the DOW. Both the interface front-end and the data base backend of MI-SAFE viewer have been integrated in the existing hardware and software environments of Deltares. This means that products of other projects can be easily linked with the MI-SAFE viewer (for instance flood risk quantification from the RISK-KIT project) and vice versa

(MI-SAFE map-products are used in RISC-KIT and the Coastal Hazard Wheel project). Furthermore the MI-SAFE intertidal elevation map-product is now linked to the EMODNET mapping effort.

Based on multiple rounds of end-user interactions, we choose to build a service that was interactive and provided information based on the merger of earth observation (EO) and numerical modelling to both non-experts and expert users. The challenge was to both provide detailed information for study sites (acting as showcase for present state-of-the-art utilizations of EO information and modelling for coastal flood risk assessments, while tracing all results back to open source protocols and databases) and to provide awareness raising level information to all non-expert users for all relevant coastlines of the world. Initially, three service modalities where identified, 1) Educational (‘Basic’), 2) Expert ('MVP') and 3) Advanced. Based on the business case development, it was decided to merge modality one and two into one online software product (MI-SAFE viewer) to streamline and minimize development effort and the future maintenance that is required. Modality 1) is activated outside the FAST study sites and produces less detailed results. Modality 3) is promoted as an application with functionalities building upon 1) and 2) but tailor-made for paying customers. In order to stimulate this, a connection has been made between MI-SAFE viewer and the Delft Dashboard environment that allows an interface to be setup so that Delft3D and XBeach models are available for any location, utilizing a geo-referenced database of map layers with all relevant input parameters. The open source XBeach model is utilized as the core numerical model, for calculating parameters relevant for flood safety engineering purposes. In this way, the MI-SAFE package has been linked to the large open source and open data communities of Deltares.

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2 The MI-SAFE viewer

The MI-SAFE package includes an on-line component (the MI-SAFE viewer) as well as a set of data and open source modelling elements all of which areavailable from the interface of MI-SAFE viewer (see chapter 4 for further details). In this chapter, an overview of the architecture and functionalities of the MI-SAFE viewer is presented. The MI-SAFE viewer allows an online assessment of the importance of any given foreshore in providing protection from waves, high water levels, and erosion, giving insight into local situations using the latest OpenStreetMap coastline of the world. The tool combines different sources of data that will be described in detail in the following chapters.

2.1 MI-SAFE Educational and Expert modes

The MI-SAFE viewer gives a first indication of the presence and potential flood risk reducing effects of foreshores. The Educational mode of MI-SAFE uses global maps of depth, elevation and vegetation derived from Earth Observation (EO) data. Via Bayesian modelling with XBeach the contribution of vegetation is calculated using a representative amount of profiles. This representation of profiles is retrieved from over 20000 profiles across the shorelines of the globe. Users can explore the contribution of vegetation to flood risk reduction at any location in a marine coastal zone.

For the field sites studied during the FAST project, the MI-SAFE viewer gives a more detailed indication of the presence and potential effects of foreshores now and in the future under various scenarios thanks to the use of site-specific wave modelling software (the Expert mode). For the field sites, the MI-SAFE viewer present better results due to the use of the finest resolution of data that could be extracted from national open data centres. Additionally, the MI-SAFE viewer can be used to inform discussions around the establishment of (new) flood protection infrastructure and the development of flood protection plans that optimally use existing ecological and landscape attributes of the coastal foreshore. As the MI-SAFE viewer uses open source data structures, all maps are accessible and downloadable. Procedures have been based on INSPIRE metadata conventions. An active open source community will be ready for any questions related to MI-SAFE. There is a seamless switch between these modes which cannot be set as a user. The Expert mode is only available in the FAST case study sites at the transects that are visualised.

2.2 The components of the MI-SAFE viewer

The MI-SAFE viewer is a web interface with functions that have interaction with the data. This is described in chapter **Error! Reference source not found.**. These functions will be discussed in he following chapters.

The following pictures give the most relevant components of the MI-SAFE viewer user interface.

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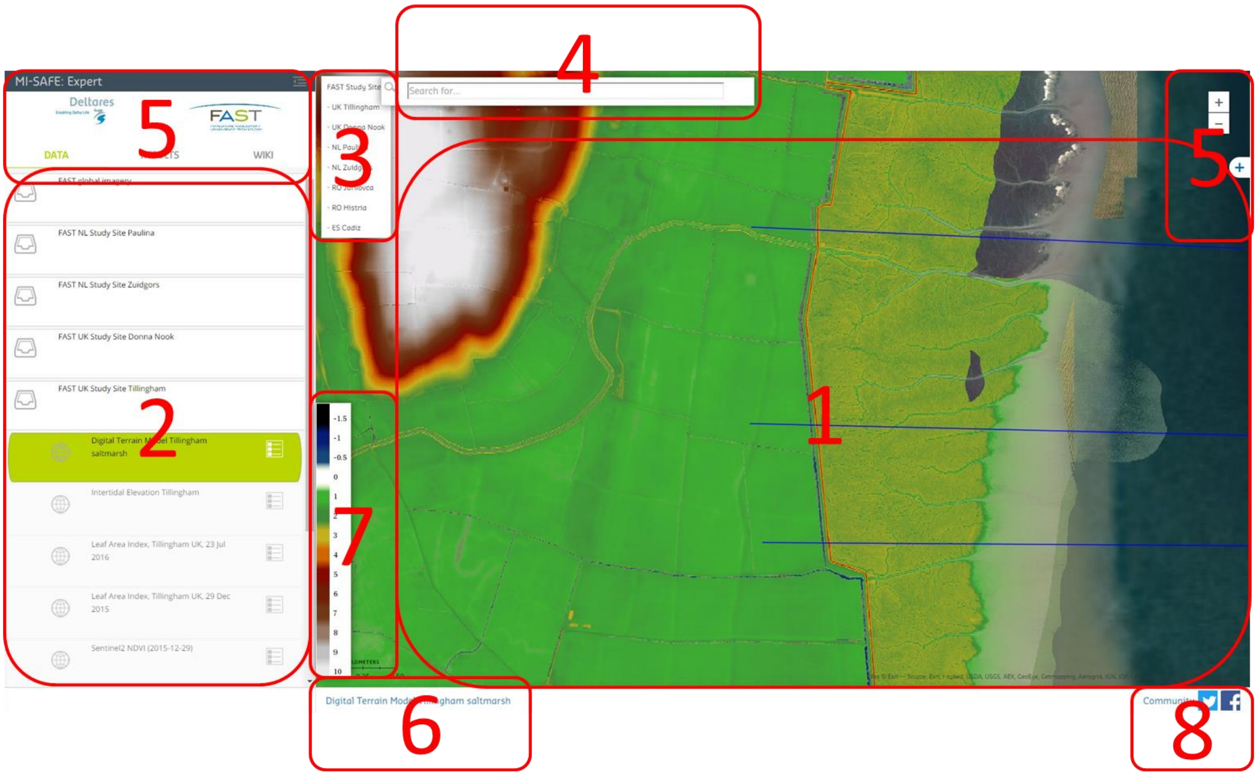

Figure 2.1 Main components of the 'data' on the MI-SAFE viewer interface. The MI-SAFE viewer is openly available at http://fast.openearth.eu.

The numbers on Figure 2.1**Error! Reference source not found.** are the main components under he 'data' page on the MI-SAFE viewer interface and mostly describe user navigation. The numbers correspond with the numbers in the screendump:

- 1 = map canvas
- 2 = layer selection
- 3 = shortcuts to data from the FAST study sites
- 4 = search bar to navigate for a place of interest
- 5 = zoom buttons, the + sign enables toggling between several background layers
- 6 = quick access to metadata of the layer selected. Selected layers become green. Hovering over the link displays the abstract of the layer
- 7 = legend of the last layer toggled on, it is possible to switch between legends on toggled layers can be done by clicking on the legend icon on the right of the layer name
- 8 = short cuts to FAST project Facebook and Twitter pages.

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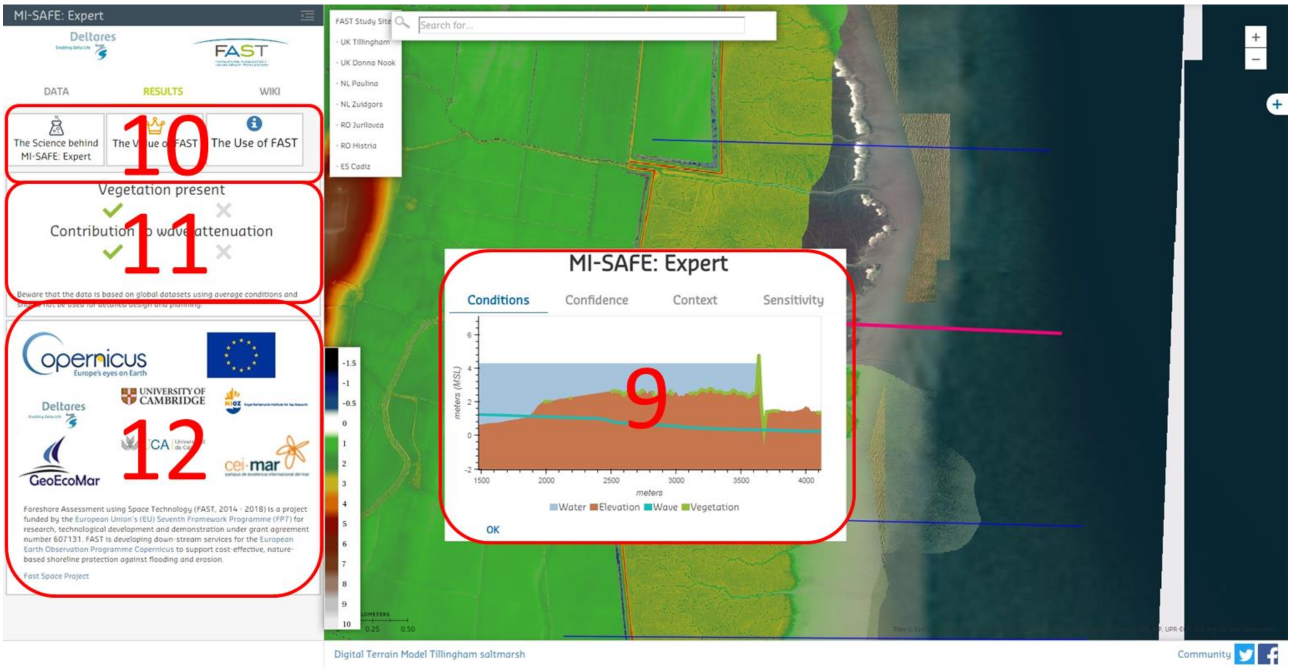

Figure 2.2. Main components of the 'results' page on the MI-SAFE viewer interface.

The 'results' page of the MI-SAFE viewer has less specific options (Figure 2.2). Including:

- 9 = MI-SAFE viewer result showing several tabs: conditions --> physical condition on the specific study site or another location anywhere in the world (in the latter case, the resolution of the conditions visualised is less than for the study sites), confidence --> displays the quality of the information in terms of confidence, context --> gives context to the information displayed, sensitivity --> model result
- 10 = Shortcuts to several subpages where detailed information can be found
- 11 = presentation screen indicating the effect of vegetation to wave attention (short version of the outcomes of the tool results)
- 12 = project information From any place on screen, a tool can be executed. How this tool works is discussed below, after a brief discussion of the available data.

2.3 Available data

The MI-SAFE viewer is populated with several layers of data that can be specified as:

- Study sites
- EU scale (with EU wide data)
- Global scale (with course resolution global data)

The difference between these scales is:

- Resolution of the data used
- The detail of model results available

Data displayed via the MI-SAFE viewer is accompanied with a link to the metadata where the origin is described. Figure 2.2**Error! Reference source not found.** shows as an example of two ayers of which the last one chosen is accompanied by a link to the metadata (see red square link to the meta data) as well as a short description.

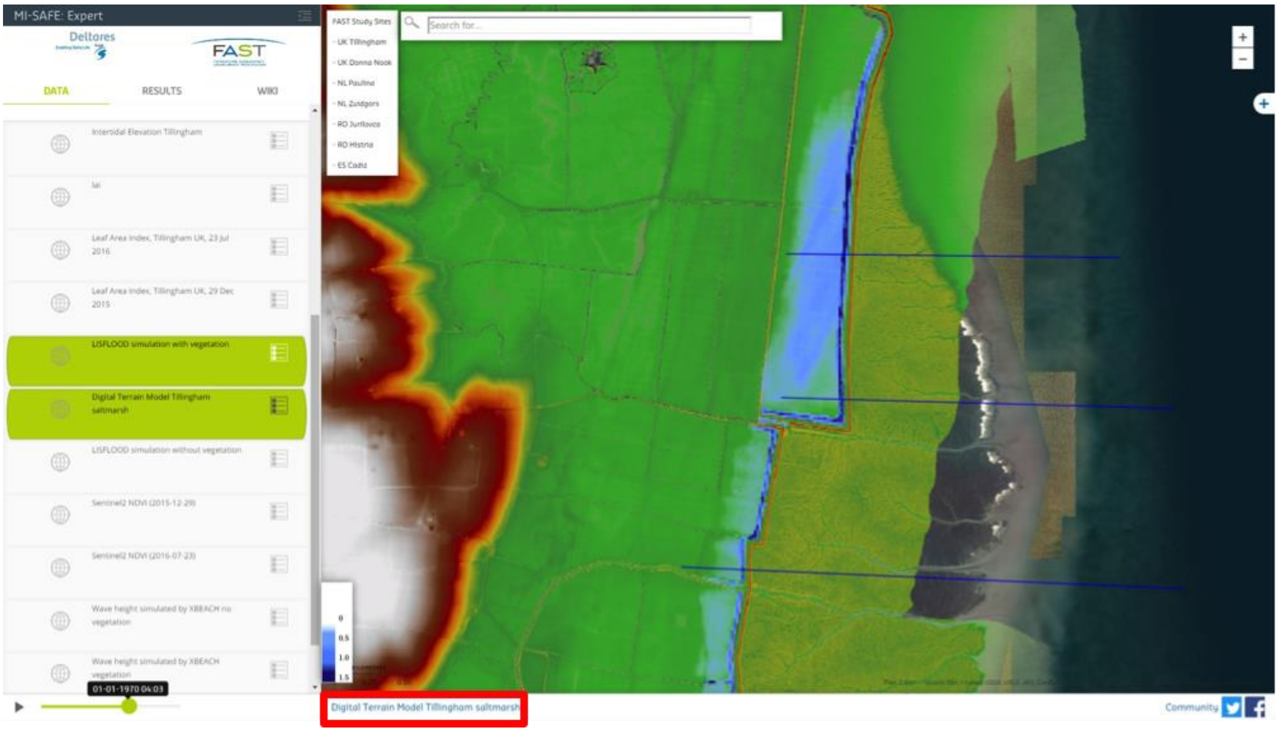

Figure 2.3. Screendump of MI-SAFE viewer with indication of link to metadata (red square)

2.3.1 Data at FAST project study sites

At the specific study sites, data is gathered and preconfigured with the highest resolution possible. For the study site Tillingham in the UK this means that a 2 m resolution digital elevation model (DEM) is downloaded in the form of a few data tiles and converted into an online dataset for MI-SAFE purposes.

Wherever possible MI-SAFE viewer and the XBEACH model analysis uses the highest resolution data available (within a certain extent). Other layers of interest at study sites have resolutions up to 20 m. Therefore 20 m is the minimum resolution used throughout the study sites with the DEM being more detailed in most cases. Higher resolutions yield in more data over a transect and thus lead to considerable longer processing times and larger images, compared with lower resolution imagery. For the FAST case study sites a base resolution of 20 m is chosen. Lower resolution imagery is not downscaled to 20, but resampled on the fly. Higher resolution imagery is aggregated using GIS procedures with the method of average resampling. Higher resolution yield long waiting times on loading and processing. In an advanced setting outside the MI-SAFE web components this is not an issue. In the Advanced case, available on request, the highest resolution data available will be used.

Chapter 4.2 of deliverable D3.9 describes for each FAST project study site, defined within the project, regional bathymetry and topography whereas chapters 4.3 and 5 describe intertidal elevation and vegetation respectively at a global level.

In case of user selected study sites in the on request Advanced mode, outside the MI-SAFE web application, data with highest resolution is the most obvious choice.

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2.3.2 EU wide data

The only EU wide dataset used consists of a reclassified image of CORINE land cover dataset (more specifically Corine Land Cover European seamless 100m raster database (Version 18.5)).

From the original 44 classes the image is reclassified to 4 classes, which are:

- Intertidal Vegetation
- Intertidal flats
- Inland Marsh
- Broadleaved forest

2.3.3 Global Data

Deliverables D3.3, D3.5 and D3.9 describes the source of global data in detail. Various sources are described and range from global coverage along the coastline of SRTM/GEBCO data to sentinel data processes in Google Earth Engine in order to derive a global product of Intertidal Elevation as shown in Figure 2.4.

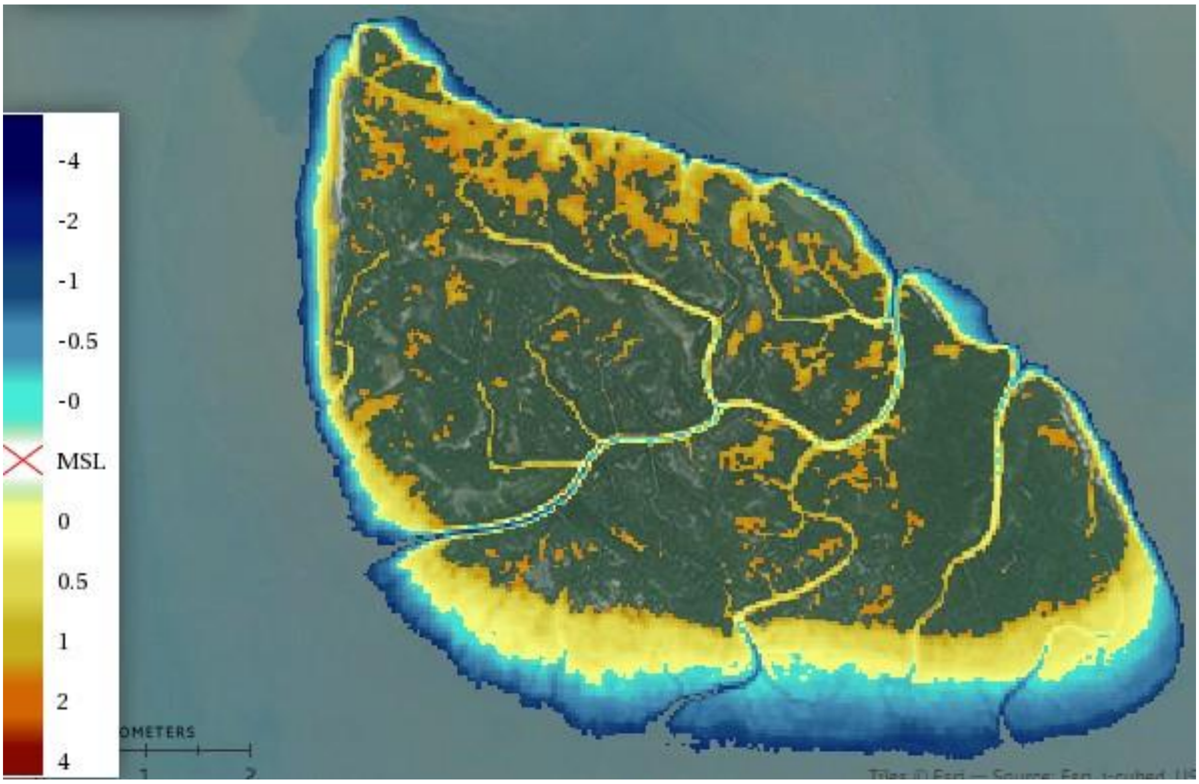

Figure 2.4. Google Earth Engine Derived intertidal Elevation dataset near the Sunderbans in Bangladesh (derived from the NASA/USGS Landsat and EU/ESA/Copernicus Sentinel 2 earth observation collections combined with CNES-AVISO+ Global tide - FES2012 tidal simulations).

In summary, the following is a list of global data sources used in the MI-SAFE viewer:

- Google Earth Engine derived Intertidal Elevation
- Globcover (global land use map)
- Global elevation and bathymetry (combination of GEBCO and SRTMv4.1)
- Tidal ranges

- Wave exposure
- Cyclone risk
- Mangrove distribution
- Google Earth Engine derive yes/no vegetation map

It is important to remember that there are various resolutions of data at various spatial scales because they form the basis for coming chapters where the actual tool is described. In general the more global the dataset is the less the spatial resolution. The exception on this rule are GEE derived maps (here we have achieved a 20 m resolution world-wide).

2.4 MI-SAFE architecture

The multi-layered client-server architecture of the MI-SAFE viewer can be subdivided into three main blocks (Presentation, Logic, Data access) corresponding to a classic *three-tier* system application (2.5), see Figure 2.5.

The first layer handles user interaction with the web platform with an instance of Delta Data Viewer (DDV) whereas the logic is handled by PyWPS services at the backend. In the Expert mode of MI-SAFE viewer, wave modelling is performed by the XBeach open-source package.

Data is stored and accessed by GeoServer and PostgreSQL/PostGIS depending of their nature (raster or vector). The GeoNetwork is used to edit and serve metadata of all the datasets involved in the computations. Last but not least, Google Earth Engine cloud services are used to transform Earth Observation (EO) data into global datasets for the project (ex: Sentinel-2 vegetation maps).

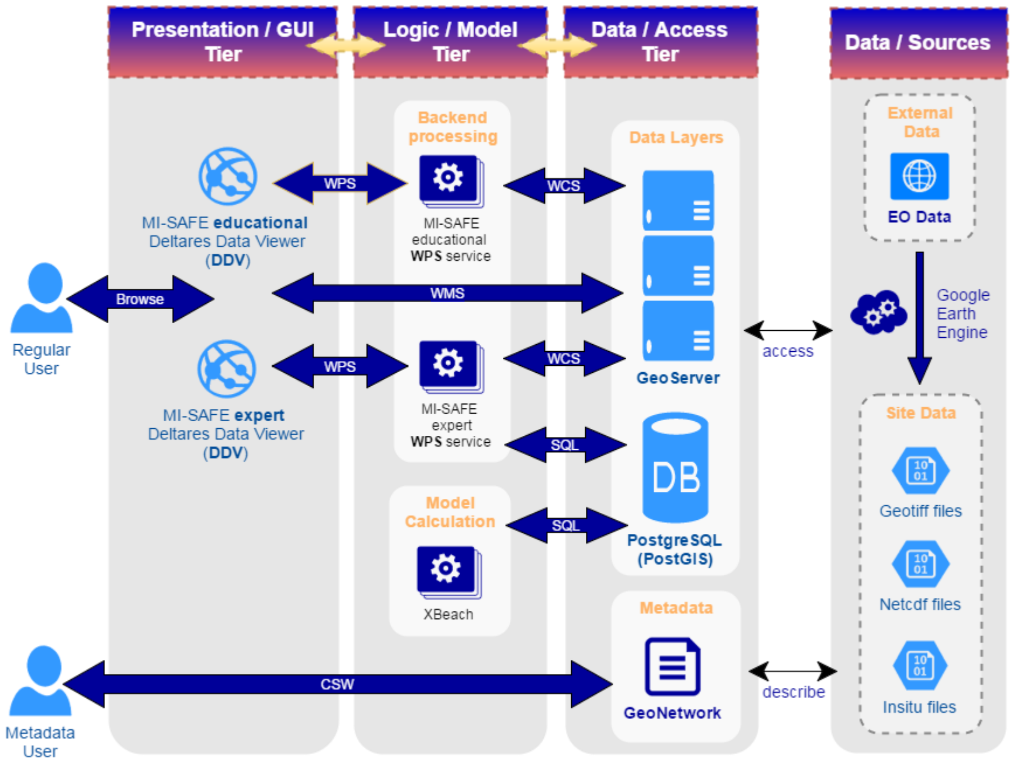

Figure 2.5. The three-layered tier architecture of the MI-SAFE viewer.

2.4.1 Presentation tier (Deltares Data Viewer)

The MI-SAFE viewer makes use of a customized instance of the Delta Data Viewer (DDV) which is an open-source GIS viewer part of the Open Earth stack that allows geospatial data visualization and also supports a variety of processes. This viewer makes data requests via the OGC WPS protocol to the backend obtaining the necessary data to produce the plots and reports. The basic information in the viewer is presented via OGC services (WMS). The viewer harvests layer definitions dynamically querying the GeoServer instance of FAST via GetCapabilities (WMS).

The viewer is based on OpenLayers and built up of 3 main parts, the canvas where the maps are shown, the table of contents where a selection of layers can be toggled on or off and the modelling part. Via Open Geospatial Consortium (OGC) services (a Web-Processing Service, WPS, in this case) data is extracted over the profile which is retrieved through a user defined point. This point is linked with the nearest coastline segment (within a buffer of 1 degree) where a perpendicular line is created. This data is then classified to certain rules and used to query the table of model results. The result is shown in a very basic way indicating whether or not vegetation is existent and or contributes to wave attenuation (see Figure 2.6).

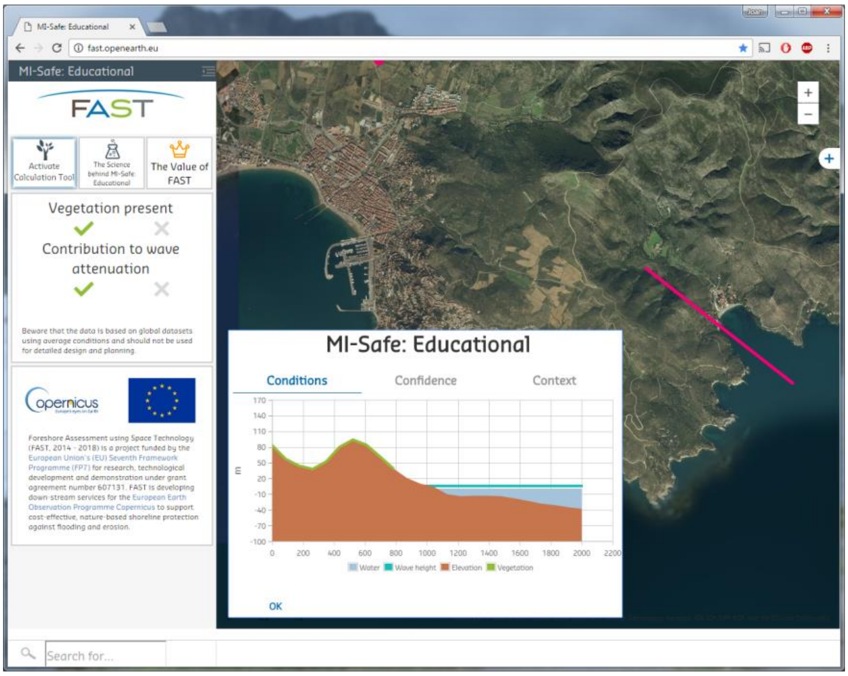

Figure 2.6. The Delta Data Viewer (DDV) instance for the Educational mode of MI-SAFE viewer.

2.4.2 Logic tier (PyWPS and XBeach)

PyWPS is used to communicate all the necessary information to the presentation tier. This python open-source implementation of the OGC WPS protocol makes use of owslib and GDAL libraries to retrieve data values via WCS with the GeoServer instance that holds the layer data. For the expert mode, PyWPS queries a PostgreSQL/PostGIS database in order to obtain the XBeach wave propagation results for the sites. XBeach is a two-dimensional community driven model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the near shore area, beaches, dunes and back barrier during storms.

Figure 2.7 presents a decision graph in order to describe the steps done when a user clicks on a point on the MI-SAFE viewer map canvas. The WPS service receives a point in the wgs84 Lat/Lon projection (epsg 4326), so a latitude and longitude. The WFS protocol is used to determine if the point intersects with the OpenStreetMap coast polygons layer hosted by Geoserver. An information message is displayed if the click is on land giving the user the possibility to choose a point on the shore. If the click is on the seaside (water) the algorithm proceeds to search if there is a transect result nearby (within 1km radius). If an XBeach pre-calculated transect is found, results are sent back to the interface (a return period of 100 years is fixed). Results correspond with the Expert mode.

If no pre-calculated transect is found nearby, a 2 km transect is drawn perpendicularly to the closest point on the shore. Around this transect; elevation, bathymetry and vegetation data from different sources is retrieved via WCS from the Geoserver. For further information on how the data is combined please refer to Chapter 3 (The Science behind MI-SAFE).

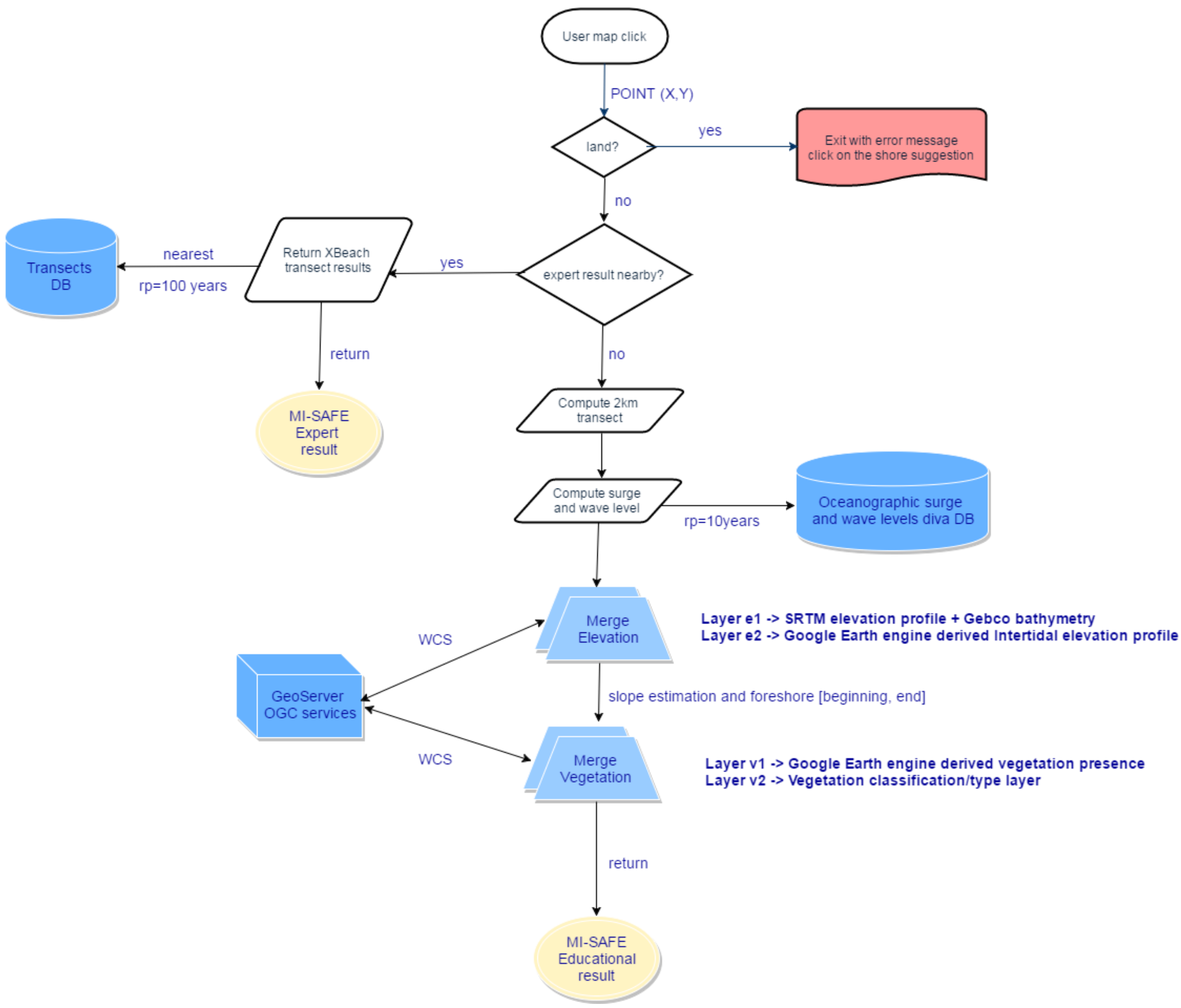

Figure 2.7. The logic behind the Web Processing Service (WPS)

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2.4.3 Data tier (GeoNetwork, GeoServer and PostGIS)

On the data layer OGC compliant solutions are used to handle raster and vector layers and the corresponding metadata. GeoServer was chosen as the solution to handle global and local raster layers in GeoTiff format and provide WMS access for visualization and WCS for coverage queries. GeoNetwork is deployed as a catalogue solution to cover the metadata editing and search part through CSW protocol. The vector outputs produced by XBeach modelling are stored into a PostGIS database that enables fast queries from the PyWPS instance of the Expert mode of the MI-SAFE viewer. Earth observation data from the Sentinel-2 mission has been processed with the Google Earth Engine in order to obtain higher resolution vegetation maps.

2.5 MI-SAFE advanced data link to Delft Dashboard

Delft Dashboard, part of the OpenEarth Initiative, is a tool to quickly create, edit and visualize model inputs (grids, bathymetry, boundary conditions etc.) for a number of hydrodynamic models (Delft3D, XBeach, WAVEWATCH III), using publicly-available datasets. It contains a number of toolboxes which are described below that assist with these tasks.

Recently, data collated as part of the FAST project have been implemented in Delft Dashboard. This includes, first of all, the 1/100 year offshore wave heights and water levels from available wave buoys; this data can be used as boundary conditions for models. Secondly, the GEE derived globally-available map showing vegetation presence/absence and the intertidal bathymetry map have been added. See Annex I for the poster of what was presented at the Delft Software Days in 2016 where these items were presented.

Delft Dashboard is part of the OpenEarth Initiative (Figure 2.8). Its user-interface and underlying functions were developed in Matlab®. An executable version, the source code (SVN), the user manual, tutorials, and much more can be obtained from https://publicwiki.deltares.nl/display/DDB/Delft+Dashboard.

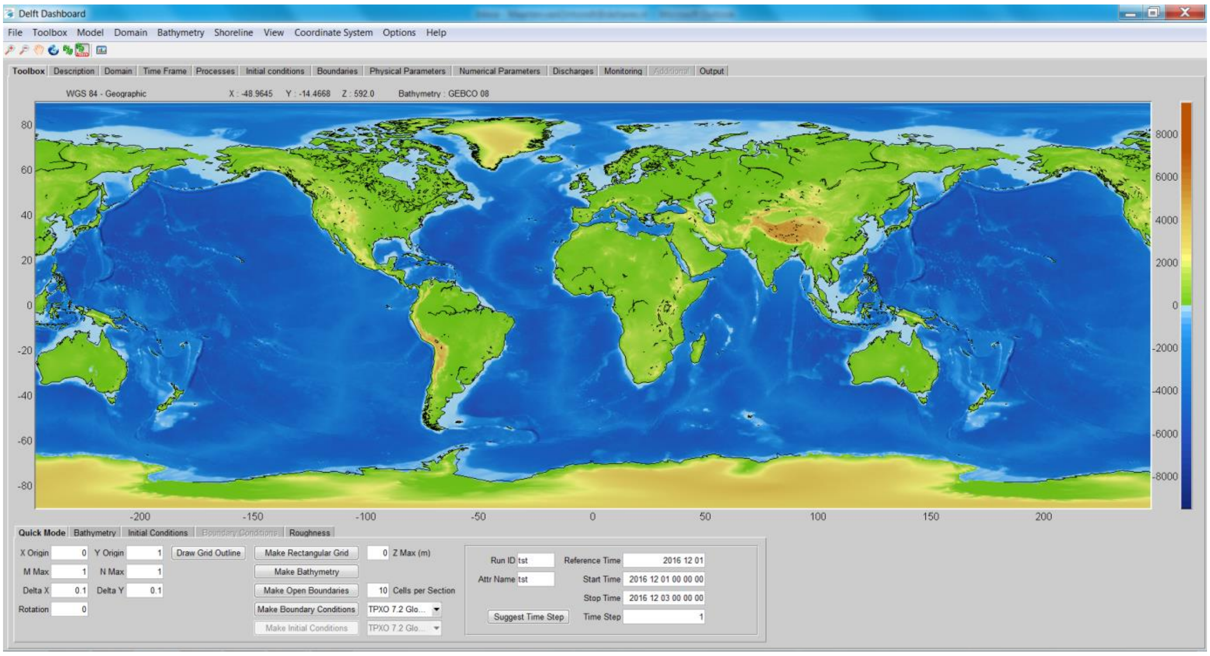

Figure 2.8. Delft Dashboard user interface.

The link with Delft Dashboard enables any user to set up an XBeach model schematization for any location in the world, while utilizing MI-SAFE map products and analyse influence of vegetated foreshores on flood risk reduction. Outputs are generated in open data formats and can be embedded in the MI-SAFE viewer (see Tillingham example in MI-SAFE viewer and Annex II for a methodological video) and in standard GIS packages.

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3 The Science behind MI-SAFE

In this chapter the scientific progress and building blocks behind the viewer are discussed. These are partly based on existing data sources, partly on new data collected and analysed within the FAST project and calculated with the XBeach model. More detailed information on The Science behind MI-SAFE can be found through a link in the MI-SAFE viewer https://publicwiki.deltares.nl/display/OET/The+Science+behind+the+MI-SAFE+tool.

3.1 Elevation

The elevation in the MI-SAFE viewer is based on several components, depending on the location of the selected shore for which results are calculated:

- Field data, with a local coverage
- SRTM coupled with GEBCO, with global coverage
- Inter-tidal elevation from satellite data, with global coverage

3.1.1 Field data

Where available, field data can be used to aid the computation of results and outputs in the MI-SAFE viewer. Within the FAST project's case study site, such data has been gathered to provide information on the topography of the surface and has been recorded at a range of scales (from mm to 100s of meters). Alongside these measurements, observations of elevation change and accretion/erosion of surface sediments have been recorded at a number of specific locations on the marsh surface, some of which have been associated with the location of sampling quadrant used for sediment and vegetation measurements and field spectroscopy. Differential GPS (dGPS) surveys were conducted at each site towards the start and end of Year 1 and Year 2.

3.1.2 SRTM coupled with GEBCO

Coastal and nearshore topography is an important factor determining the risk of flooding and thus features highly in the MI-SAFE application. The elevation of the surface over which the tides and waves travel determines how high the water level and the waves will be when they reach the most landward lying natural or artificial barrier. In addition, the type of surface and type of barrier determines how easily it is altered by tides and waves and how likely it is to suffer erosion. Hard rock coasts that rise up from the sea are less likely to suffer erosion than soft cliffs or sandy coasts. Topography and sediment stability therefore are very important factors. Several datasets are identified as useful for the characterisation of topography in FAST, these are:

- SRTM Topography (http://srtm.usgs.gov/)
- GEBCO Bathymetry (http://www.gebco.net/data_and_products/gridded_bathymetry_data/)
- ASTER (http://asterweb.jpl.nasa.gov/gdem.asp)

For the global version of the MI-SAFE viewer a derivative product called SRTM15_plus is used. It offers a continuous global coverage of bathymetry and topography. The SRTM15_plus dataset is created by the Scripps Institution of Oceanography (http://topex.ucsd.edu/index.html). This dataset is used for viewing since it is a continuous dataset at global level with low resolution. For analysis a more detailed dataset is created using the SRTM3 v4 and GEBCO data. The finest resolution of approximately 90 meter is combined where GEBCO is rescaled to 90 meter and interpolated to the SRTM tiles. To reduce computation time this is done for tiles along the OSM shoreline of the coast.

3.1.3 Intertidal elevation

Precise elevation of the intertidal (foreshore) is crucial in the performance of the MI-SAFE viewer, because this is the area where the actual wave attenuation takes place.

Whilst in theory elevation and bathymetry data sources can be combined (see Elevation paragraph above) to create a continuous DTM that seamlessly covers intertidal regions, in practice a number of issues limit the usefulness of this approach:

- Intertidal regions are often missing from both land and seabed elevation data sets.
- Spatial and vertical resolutions may be below the minimum requirements of MI-SAFE (i.e. vertical accuracy of about 1 m).
- Most of the world is 'data-poor'; meaning lower quality and reduced open-access to elevation data.

EU/ESA's Copernicus, high resolution Sentinels (S1 and S2) and the NASA/USGS Landsat missions can help to fill this narrow, yet crucial gap. Extended temporal coverage means that a large number of images with different tidal elevations are available for most coastal regions. Per pixel identification of surface water coverage or absence (using algorithms made available in the open source library of FAST) from this large collection of images allows composite, time-ensemble averaged (TEA) images of the probability of inundation to be built up in tidal coastal zones. With calibration, these can be converted into inter-tidal elevation maps (Mason et al. 1995; Niedermeier, Hoja, and Lehner 2005; Murray et al. 2012). However, this technique is usually applied to relatively small regions and often includes in situ calibration via field measurements of intertidal elevation; hence the challenge for MI-SAFE was how to convert TEA inundation probability to elevation at a global scale without principally relying on field data?

To solve this challenge, as a first approximation, we assumed that:

- TEA water indices can be transformed to inundation probability [0,1] by normalising by the spatially-averaged, TEA water indices of regions identified as land and water, respectively.
- Once normalised, for a single pixel in an inter-tidal zone, the TEA inundation probability represents the long-term average of tidal height.
- If the inundation probability is derived from a collection of images that span a period of time similar to the tidal epoch, i.e., the time period over which tidal height statistics are derived (commonly 19 years), then pixels with a probability of 1 represent permanent water and have elevations less than or equal to the lowest astronomical tide (LAT), whereas land ($p = 0$) represents elevations more than or equal to the highest astronomical tide (HAT). By deduction, $p = 0.5$ is then equivalent to mean sea level (MSL).

Development and production of inter-tidal elevation maps covering most of the global coast were carried out using the Google Earth Engine (GEE) computing platform; this facilitates rapid development and testing.

3.2 Waves

The wave conditions shown in the MI-SAFE viewer are based on several components, depending on the geographical location selection for the calculation:

- Field measurements, with a local coverage
- ERA interim off-shore waves, translated to nearshore depth limited waves, with global/local coverage

3.2.1 Field measurements

To acquire the results of the modelling exercise conducted with XBeach for a range of different types of vegetated foreshores and a range of exposure to waves and tides, the XBeach model was validated and calibrated against detailed water level data recorded using high frequency (4 Hz) dynamic water pressure measurements. This was done to resolve even small (2 Hz frequency) waves through the use of bed-mounted pressure sensors at a series of eight vegetated foreshores in Europe, ranging from reed beds in Romania (outer Danube Delta) to Sarcocornia salt marsh (Bay of Cadiz, Figure 3.1), and NW European estuarine and open coast salt marsh (The Netherlands and United Kingdom respectively). Data recording took place with a telemetered data logging system that captured waves and water levels during almost every inundation of the vegetated foreshores from early autumn to late spring over one year. The Romanian field sites Jurilovca (Razelm) and Histria (Sinoe) experienced continuous inundation, albeit with varying water levels, such that data acquisition at these sites varied from that at the United Kingdom, the Netherlands and Spanish sites with wave records triggered every 8 hours (three times per day). Water pressure records acquired in this way were processed into water depths, wave spectra, and summary wave statistics by the University of Cambridge, using tried and tested programming routines (Möller et al. 1996 and Möller and Spencer, 2002).

Figure 3.1 Wave, vegetation and topographic measurements in transect in the Cadiz Bay field site, Spain, year 1.

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3.2.2 ERA interim

Hydraulic boundary conditions in the form of off-shore wave data for return periods (Tr) of 1, 10 and 100 years are extracted from the ERA-Interim dataset. Waves are generally lower in the tropics (e.g. less than 2 m between -30° to + 30°) than in temperate zones (where Hs > 5m between 40°-70°).

As the ERA-Interim wave data is based on offshore characteristics, waves are translated to onshore conditions by comparing the waves from ERA-Interim with a depth limited wave. If the depth limited wave height is smaller, this wave height is used for calculations whereas the period is maintained. The wave direction is not taken into account explicitly; the wave direction is assumed to be coast-normal, as it would be during a worst-case-scenario storm, for which an assessment of the protection function of the foreshore is likely to be most important. This approach seems to work well for exposed coastlines but likely leads to over-estimations of wave heights for more sheltered environments.

For the FAST case study sites for which more accurate hydraulic boundary conditions were available, these were used for the determination of the incoming wave height.

3.3 Water levels

Wave attenuation over foreshores is typically most relevant during storm conditions that create a surge (water level set-up) in combination with high tidal levels. For the MI-SAFE viewer, a water level that has a probability of occurrence of 10%, i.e. once in 10 years, is considered to be the most relevant: this represents a storm that is both frequent enough to be relevant to users' needs for planning coastal protection (a 1/100 or 1/1000 year condition may seem too extreme) and severe enough to be a serious threat to coastal regions. The representative water levels or hydraulic boundary conditions are derived from a global D-Flow Flexible Mesh model (Muis et al., 2016, Figure 9) that includes tides, storms and hurricanes. The output of this model is mapped to Dynamic and Interactive Vulnerability Assessment (DIVA) segments, so local anomalies can occur for coasts with irregular shapes (bays, estuaries). More extreme or locally tailored conditions are included in the ADVANCED modality of the MI-SAFE viewer, which can take into account hydraulic boundary conditions that are specified by users -e.g. in local coastal management guidelines- or derived from dedicated modelling or field observations at the relevant location.

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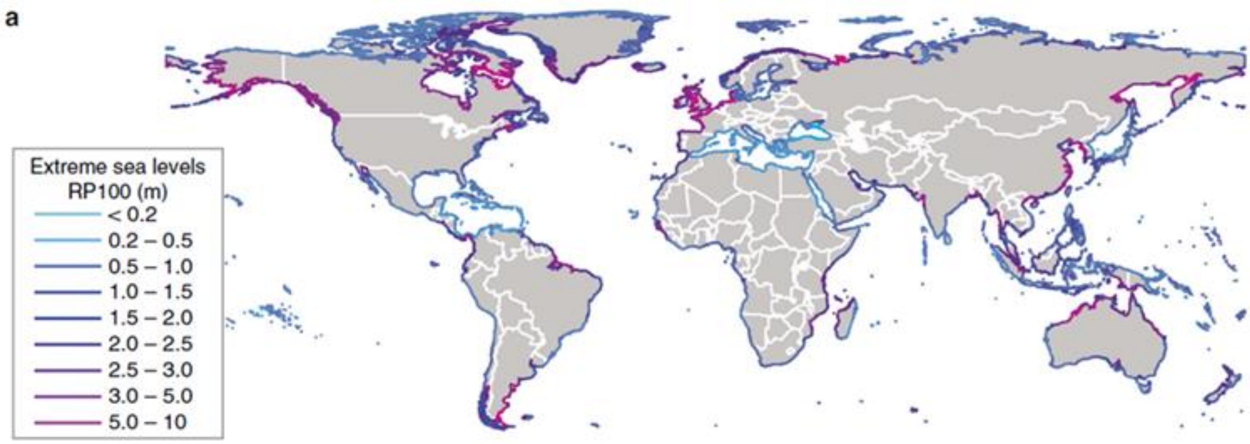

Figure 3.2. Global extreme water levels (tide + surge) for a return period of 100 years. From Muis et al. (2016).

3.4 Vegetation

The effect of vegetation in the MI-SAFE viewer is based on several components, depending on the selected location of the calculation:

- Field data, with a local coverage
- Earth Observation products of vegetation, with global/local coverage

3.4.1 Field data

For each of the eight FAST case study sites (two each in Romania, Spain, the Netherlands, and the UK), vegetation species richness, percentage cover, and height was recorded seasonally in 1 x 1 m^2 survey plots over a period of one year. In addition, a ‘photo frame’ was used to capture the density of the vegetation layer as seen from the side (and as experienced by water flowing over the surface) Möller, 2006. The vegetation photographed in this way also harvested (an area of 20 cm x 60 cm) to determine its biomass and, where appropriate (grass species), the number of stems per unit surface area. At the Romanian sites (Figure 3.3), tall reed was present and a sub-sample of stems was harvested from each survey location instead of using the photo frame area for harvesting.

In the MI-SAFE viewer this field data is used as input to the XBeach model. This was used to validate the performance of the XBeach model on the FAST case study sites and also to derive a set of representative vegetation characteristics per vegetation type (reed, marsh) for global application.

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Figure 3.3. Vegetation measurements of the reflectance of reed beds in the Romanian field site.

3.4.2 EO products of vegetation

We provide the following vegetation products derived from Earth Observation:

- vegetation presence/absence (a global product)
- vegetation type (a product on European scale), and
- biophysical characteristics of the vegetation (examples for the FAST case study sites)

3.4.2.1 Vegetation presence/absence map, Global coverage

The amount and type of vegetation greatly influences how waves are attenuated as they cross the foreshore. To enable global foreshore assessments of wave attenuation by vegetation, a high resolution global map of vegetation presence and absence is paramount. Readily available maps such as GlobCover and Corine Land Cover (CLC) have resolutions that are too coarse (i.e. 300 to 100 m resolution) for the purposes of MI-SAFE, where a resolution of 10s of meters is required.

A global binary (presence/absence) vegetation map for coastal areas was created as input for the MI-SAFE viewer and combined with GlobCover and Corine Land Cover to determine vegetation type (reed, marsh, mangrove). The presence of vegetation is determined using the Normalized Vegetation Index (NDVI) values which were calculated using Sentinel-2A and Landsat-8 products, using the Google Earth Engine (GEE).

Steps taken in order to derive a global vegetation map:

1) Coastline grids and sub-grids.
A global map is separated into grid cells and sub grid cells. Satellite images are collected only of the grid cells which contain a coastline. This helps prevent downloads and processing of redundant satellite images. Global coastline is derived from the OpenStreetMap website.
2) For each grid cell a cloud-free mask image is derived using QA60 band for Sentinel-2 and QA band for Landsat-8. Using this cloud free image collection NDVI value is calculated for each pixel in each image (esa.int). Pixels have a 10 m resolution for Sentinel-2 images and 30 m

resolution for Landsat-8 Images (Figure 3.4). For each pixel all available images are collected and stacked, i.e. image 1 till n^th image. Per pixel, the NDVI value is calculated for the entire stack for all available images. This gives an image collection of pixels containing NDVI-values for a specific x,y coordinate and for all different moments in time.

3) A vegetation mask is built by defining a NDVI threshold for each x,y location. Based on the yearly NDVI average and NDVI amplitude, the threshold is chosen. This means that each location has a different NDVI value above which pixels are determined as vegetation, or non-vegetation, Figure 3.5. See Zhu et al, (2012) for a detailed explanation of this method.

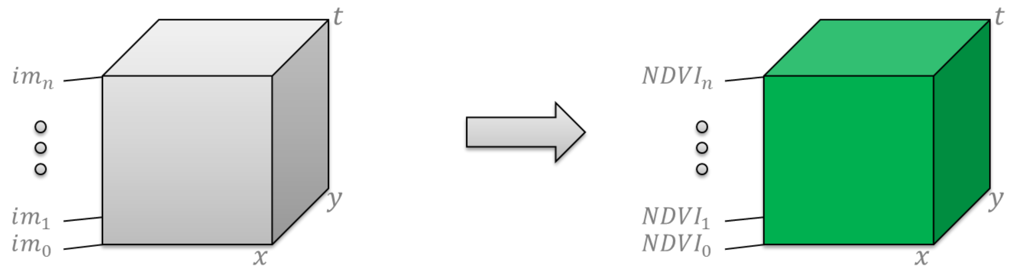

Figure 3.4. For each pixel all available images are collected and stacked, i.e. image 1 till n^th image. Per pixel, NDVI value is calculated for the entire stack for all available images. This gives an image collection of pixels containing NDVI-values for a specific x,y coordinate and for all different moments in time.

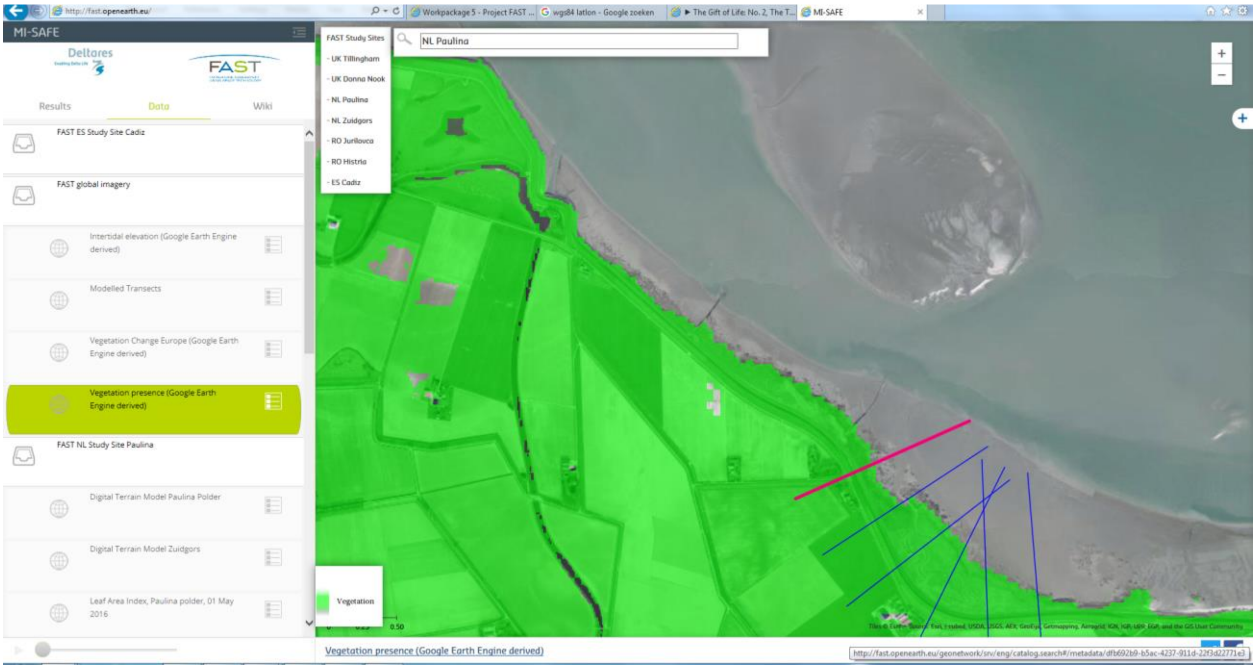

Figure 3.5.Global coverage Yes/No vegetation map. Example result for the area surrounding the NL Paulina study site.

3.4.2.2 Vegetation type

Vegetation type is based on either GlobCover data (Global coverage, 2009) or Corine Land Cover (CLC, European coverage, 2000-2006) information that was reclassified to suit MI-SAFE needs (Figure 3.6). For non-temperate zones on a global level, a global distribution of mangroves (Giri et al., 2011) indicates whether the vegetation encountered is mangroves or other vegetation. How the properties of the different vegetation types are characterized for the wave attenuation

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calculations in the MI-SAFE viewer is described in 'Wave attenuation modeling: Characterising vegetation types'.

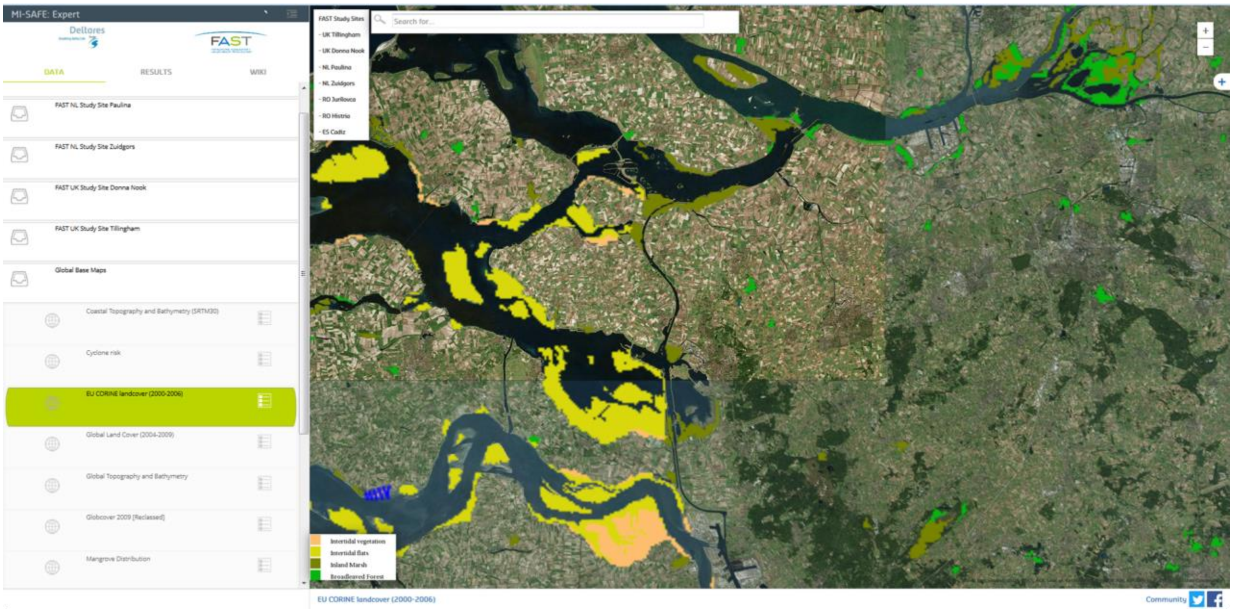

Figure 3.6. The four vegetation types on a map of the southwest of the Netherlands. The green area in the upper right is the Biesbosch area with willows and reed beds. The yellow areas in the west are unvegetated intertidal flats in the Eastern- and Western Scheldt. At the fringes of these tidal environments, saltmarshes are visible in orange (e.g. 'Land van Saeftinghe') in the south and the FAST 'Zuidgors' fieldsite in the southwest, covered by blue lines.

3.4.2.3 Intertidal vegetation (salt marshes)

Intertidal vegetation is derived from the CLC class Salt marshes (421): areas submerged by high tides where vegetation dominates. The vegetation cover of such marshes can vary considerably between locations and throughout the year (Figure 3.7). For example, *Spartina* spp stands can well be 70 cm high during summer, whereas *Salicornia* spp. can be nearly absent in winter. The properties as observed by Möller (2006) (biomass and photo frame measurements of image obscuration) were selected for use in MI-SAFE, because they are for a mixed marsh typical for North-Western Europe and because they have been shown to be related to observed wave dissipation. Moreover, the drag coefficient of typical NW European marsh vegetation cover has been derived from large-scale flume experiments under (near) real world wave conditions (Möller et al., 2014).

Figure 3.7. Salt marsh vegetation at Cadiz Bay (ES) marsh, 2015

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3.4.2.4 Inland marsh (reed beds)

Reed beds are of interest for inland locations such as lakes that are often fringed by reed beds, and for the Romanian study sites of FAST where large reeds grow in coastal lagoons. The CLC map does not account for reed beds as such, but are based on class 411 Inland marsh. As a result, the MI-SAFE viewer applies reed bed properties to every inland marsh, also the ones predominantly made up of lower shrubs. This might overestimate the wave attenuation capacity of such marshes.

For the moment, the properties of the reed beds at the Romanian sites (Figure 3.8) have been used because these are readily available and because they represent the situation at the study site, which enables a comparison with local observations of wave attenuation. It should be noted that these are possibly taller reeds than usually found along lake banks. More references exist (e.g. Moeller et al., 2011) and can be used when MI-SAFE advanced applications to new sites are requested.

Figure 3.8. Wave breaking in Romanian reed vegetation

3.4.2.5 Broadleaved forest (riparian willow forests and mangroves)

All areas classified by CLC as ‘broad leaved deciduous forests’ (class 311) are considered to be willow forests if they are located in Europe, where no mangroves occur. The CLC class also contains many forests far from any large water body, but these are not relevant as they will not be queried by users of the MI-SAFE viewer. Forests hardly occur directly adjacent to the coastline, and if they do they are usually coniferous so they will not lead to a false positive identification as willow forest. As a consequence, riparian forests are the most likely forests to be identified in this class. For areas outside Europe, the reclassified GlobCover data are further reclassified into willows in temperate regions and mangroves between -30° and +30° latitude. The world mangrove map of Giri et al. (2011) was not used to determine vegetation type because testing at several locations around the globe revealed that the location of mangroves on this map is not accurate enough for the purpose of the MI-SAFE viewer.

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The composition, and consequently tree size, of riparian forests differs considerably among floodplains but willows are very common in European floodplains. The age and size of willows depends strongly on the management of floodplains: in natural rivers they are older and taller than along strictly managed rivers, where they can be cut regularly to prevent flooding as a result of the additional hydraulic resistance they cause. Such managed areas are more likely to be of interest, and the MI-SAFE viewer should not overestimate the wave attenuating effect. Therefore, the willow dimensions are chosen to be representative of relatively young, regularly trimmed trees. Data are available from sites in the Netherlands: commonly found regularly cut pollard willows ('knotwilgen') of several years old and young willows (less than 1 year old) of a field especially planted for wave attenuation in front of a levee near Fort Steurgat, Werkendam (Figure 3.9).

Like willows, the tree size and density in mangrove forests varies substantially among forests, depending on species composition and age of the forest. For the MI-SAFE viewer, the properties of the trees occurring at the seaward side (regular inundation, high salinity) of the mangrove forest are the most relevant because this is where most of the wave attenuation takes place. Moreover, further inland, the forest likely becomes more heterogeneous and mixed with terrestrial species. The two globally representative species for this zone are the red mangrove (*Rhizophora* spp.), which is characterized by prop roots (Figure 16d), and the black mangrove (*Avicennia* spp.), which is characterized by pneumatophores (Figure 16e). As deducing the type and size of mangrove trees from EO data is not (yet) possible, the MI-SAFE viewer relies on literature observations of dimensions of these two species, as summarized by Janssen (2016). To avoid overestimation of wave attenuation in young or very cyclic mangrove forests, the mangrove dimensions are chosen to be representative of young, pioneering mangroves up to 3 m tall.

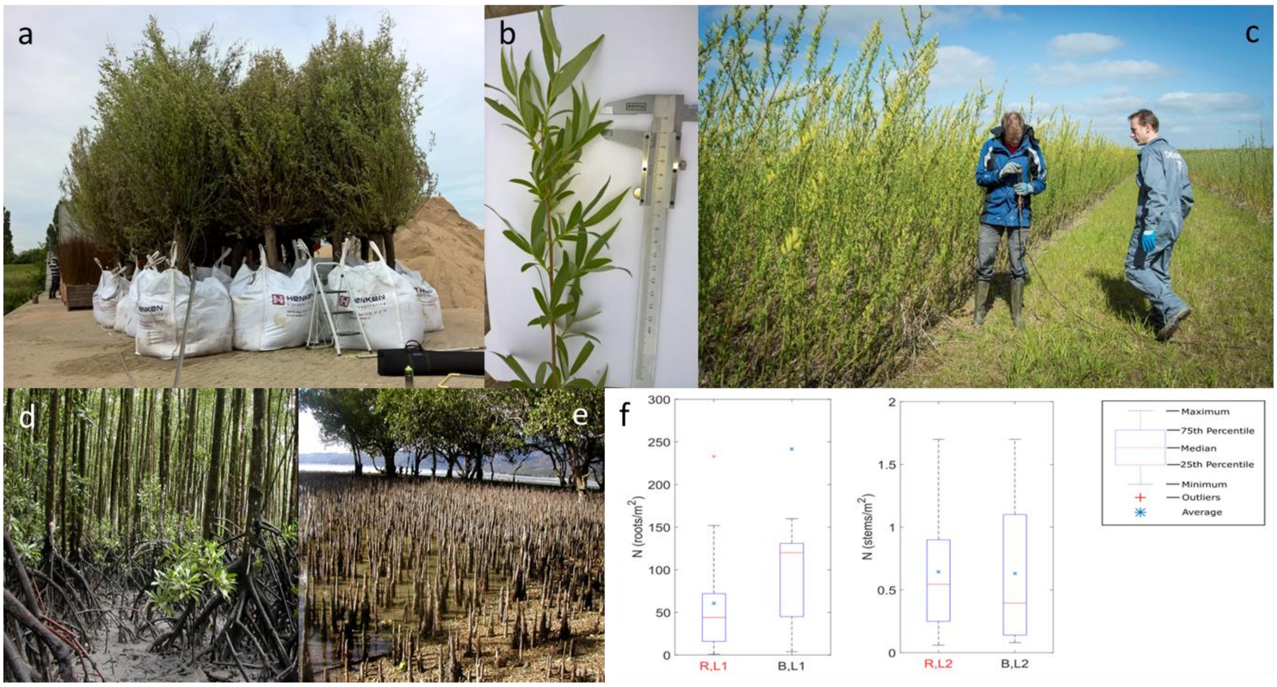

Figure 3.9. Willows and mangroves used to characterize vegetation properties. a) and b) Pollard willows (~10 years old) that were measured in detail for an experiment on wave attenuation near Ridderkerk (NL). c) Young willows planted and measured by Deltares staff in front of a levee near Fort Steurgat (NL). Examples of d) red and e) black mangroves, which were characterized by Janssen (2016) based on a literature study.

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3.4.2.6 Biophysical characteristics of the vegetation

The globally applied methods to derive vegetation information give a broad overview of vegetation occurrence and the type of vegetation. However, with each of these types, the characteristics can vary spatially and temporally. To incorporate these variations into the MI-SAFE viewer, EO-based maps of the biophysical characteristics of the vegetation were created in different seasons for each study site and are made visible in the data layers of the viewer.

Normalised Difference Vegetation Index (NDVI) of the foreshore

One measure of surface reflectance in the red and near infrared that may be affected by some of the biophysical characteristics of vegetation that is often used to characterise vegetation cover is the Normalized Differential Vegetation Index (NDVI) of both the saltmarsh and the adjacent mudflat and waters. NDVI is based on surface reflectance in the red (RR) and near-infrared (RNIR) part of the electromagnetic spectrum, as follows: NDVI = (RNIR-RR) / (RNIR+RR). Hence, it has no units, and ranges from -1 to 1. As chlorophyll absorbs notably in the red, whereas the leaf structures of macrophytes scatter in the near-infrared, values typically increase with increasing cover, biomass or health of the vegetation. NDVI may also differ per vegetation type. Values of NDVI <0 typically indicate water. On the mudflat, higher values indicate higher biomass of microphytobenthos biomass, higher biomass, density and health or different types of macroalgae and seagrass. The product implemented in MI-SAFE is based on NDVI calculated from Sentinel-2 MSI images after atmospheric correction (using Sen2Cor in ESA's Sentinel's Application Platform SNAP), for images of different seasons. Below are examples for such NDVI products at a case study site in the Netherlands (Paulina), see Figure 3.10. In these products, the land is masked. Spatial resolution of the NDVI product is 10 m. Note that with the RapidEye sensor (commercial) the resolution can be increased to 2 m.

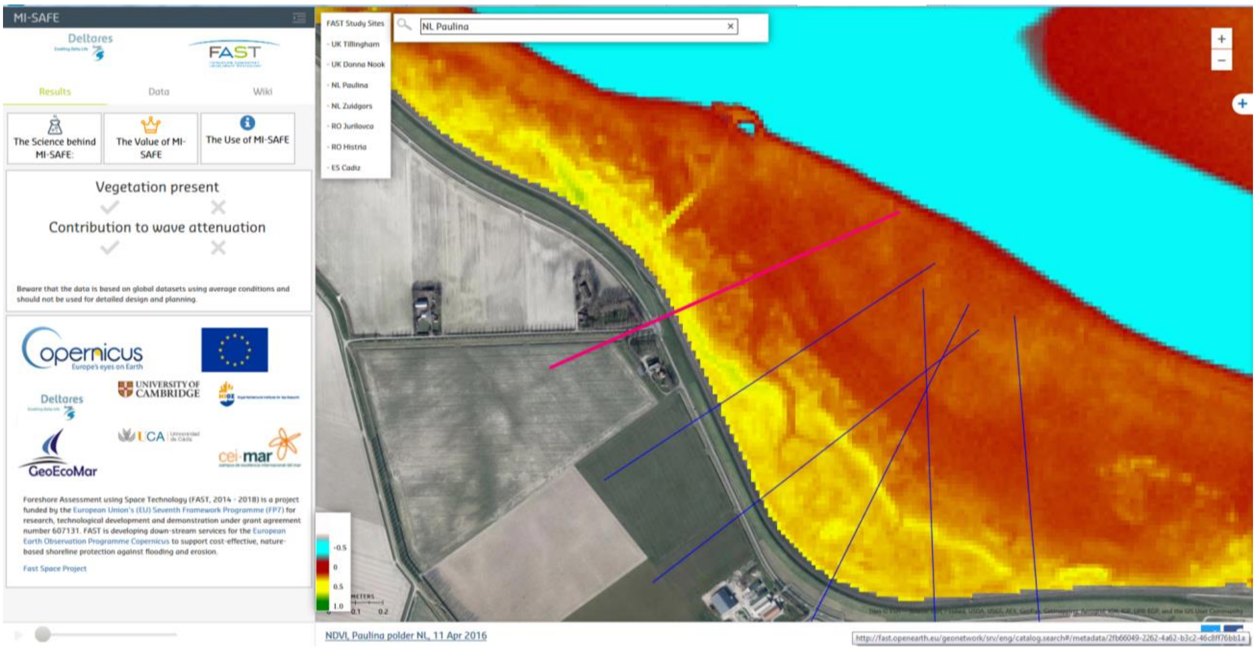

Figure 3.10. Sentinel 2 NDVI result for NL Paulina study site

Leaf Area Index (LAI) of the marsh vegetation

A core biophysical variable represented in the MI-SAFE viewer is Leaf Area Index of the marsh. Leaf Area Index refers to green leaf area per unit ground area. It is derived from Sentinel-2 MSI level 2B biophysical products. The algorithm for Leaf Area Index implemented in such level 2 biophysical products is based on a neural network approach, trained on a database of vegetation characteristics and associated Sentinel-2 top of canopy reflectances. It is produced in SNAP from images after atmospheric correction. The product as implemented in the MI-SAFE viewer refers to Leaf Area Index of the marsh only (where marsh is defined for NDVI>0.3). Areas outside the saltmarsh, either subtidal area or emerged tidal flat are set to 0, and land is masked. The maps can be produced for any vegetated foreshore, but in the MI-SAFE viewer, layers refer to the case study sites for images of several dates/tidal conditions. See Figure 3.11 for an example of seasonal variation of the marsh at Tillingham (UK).

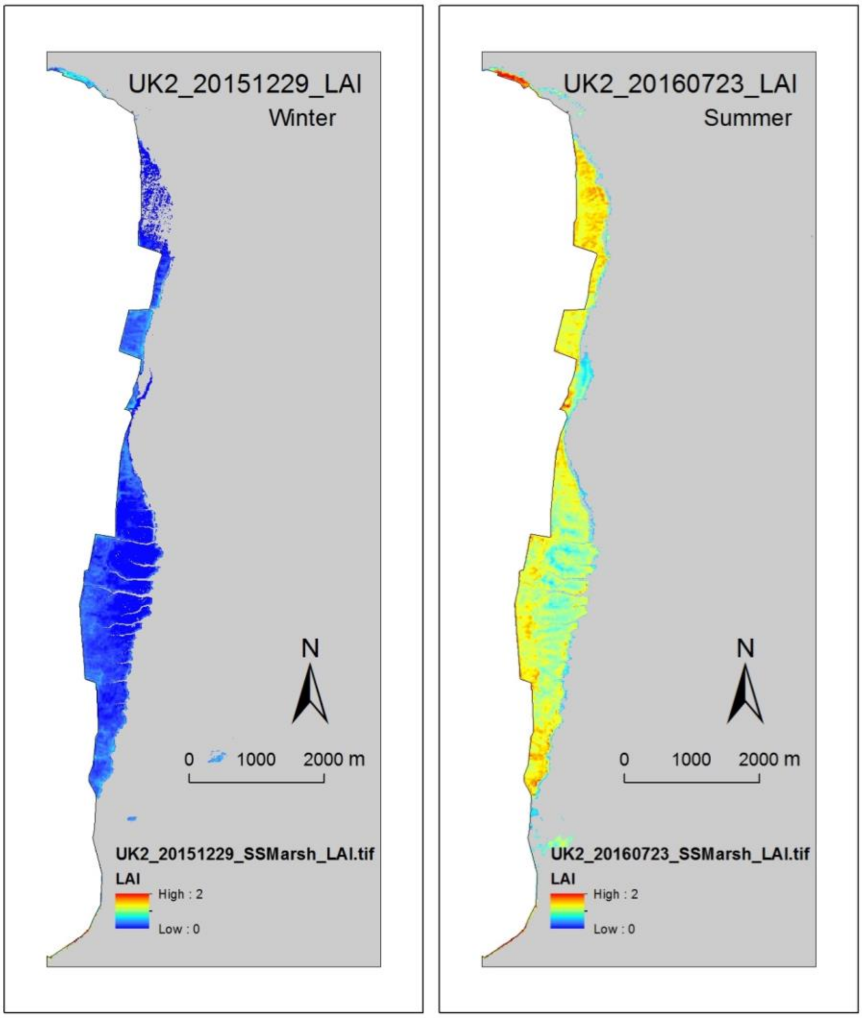

Figure 3.11 Seasonal variation in vegetation cover (LAI) at the Tillingham marshes, derived from Sentinel-2 MSI images. Left: December 2015, Right: July 2016. Darker colours represent higher LAI, i.e. more vegetation

3.5 Wave attenuation modelling

In order to quantify wave attenuation by vegetation for a given salt marsh or mangrove coastline, the MI-SAFE viewer uses the numerical modeling software XBeach (van Rooijen et al., 2016). Xbeach is a depth-averaged, two-dimensional process-based model that solves the time

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dependent short wave action balance for the entire wave group, suitable for simulating wave attenuation over foreshores. XBeach has three wave energy dissipation processes relevant for MI-SAFE simulations: dissipation due to (depth-induced) wave breaking, dissipation due to bottom friction and dissipation due to vegetation. XBeach also has three simulation modes, from simple to advanced: stationary, surfbeat and non-hydrostatic. The stationary mode is fast but lacks wave groups (surfbeat) that are important for wave height variations near shore. The non-hydrostatic mode is physically the most complete but at substantial computational cost. The surfbeat mode does represent the effects of wave groups at reasonable computational cost and represents the effects of vegetation via the well-known relations of Mendez & Losada (2004), and is therefore selected as the most useful mode for this application.

XBeach requires four parameters to represent the presence of vegetation:

1) Length or height h (m);
2) width or diameter d (m);
3) number of stems per horizontal area n (N# m^{-2});
4) drag coeffient C_D (-).

The product of all parameters is the vegetation factor, which can be regarded as an 'effective biovolume' related to wave attenuation. The product of h, d and N, is similar to (an exact conversion is still under development) the leaf area index (LAI), which is derived from EO. For deriving representative properties based on biophysical characteristics under 'Data', three principles were followed for the Educational, globally applicable, version of MI-SAFE:

1) The vegetation factor should be relatively conservative, so as not to give an overly optimistic estimate of wave attenuation. Thus, plant dimensions are chosen with winter conditions and relatively small individuals in mind. The a priori choice of a drag coefficient may lead to some error, because the coefficient not only depends on the plant properties but also on the hydrodynamic conditions. Therefore, a relatively conservative estimate is made with large waves (that give large Reynolds/Keulegan-Carpenter numbers that are associated with low drag coefficient values) and the flexibility of the vegetation in mind. This can be refined once more reliable drag coefficient estimators are available, e.g. based on observations under (near-) design conditions in large-scale flume experiments. Presently, such experiments only have been performed for salt marshes, not for reeds, willows or mangroves.
2) The vegetation factor should be representative for all occurrences of a particular type, not just for a specific site.
3) The vegetation factor should be large enough and differ enough between vegetation types to meaningfully differentiate the effects of different vegetation covers from each other.

For the Expert version, which benefits from the information gathered on the study sites, the actual vegetation properties have been used. Here the following principles apply:

1) The vegetation factor should be relatively conservative, so the plant dimensions are based on in-situ observations in winter conditions. The vegetation cover (spatial density) is based on the winter LAI maps; transforming EO observations directly to a full set of plant dimensions is work in progress.
2) The drag coefficient is based on plant dimensions as well as the hydrodynamic conditions characteristic for the site.

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The sensitivity of the wave attenuation modelling to different settings of vegetation parameters and to spatial and seasonal variations in vegetation cover has been studied in Deliverables 5.4 and 5.2 respectively.

3.5.1 Characterising vegetation types

The table below (Table 4) shows how the different vegetation types are characterised through XBeach input parameters. Note that, at present, these basic assumptions are used only if global information is available in the Educational version of the viewer. In the Expert version, the local in-situ and EO data are used to derive vegetation properties.

For salt marshes, the values were defined based on the field observations at the FAST field sites, the properties of the temperate marsh tested by Möller et al. (2014) and the global inventory of Songy (2016). The drag coefficient of 0.19 is the lower limit found in the large flume tests by Möller et al. (2014); Songy (2016) matched field observations by Vuik et al. (2016) using a drag coefficient of 0.4. These values are well below the textbook value of ~1 for stationary flow through cylinders due to the flexibility of the vegetation.

The mangrove parameters are based on the inventory of Janssen (2016), who synthesized observations of a.o. Cole et al. (1999), Narayan (2009), Mazda et al. (2006) and Horstman et al. (2012). Here, the representative drag coefficient could not be derived from experimental results since high quality observations on wave attenuation by mangroves under storm conditions do not exist. Instead, the theoretical value for a circular cylinder was used as mangrove trunks can be considered to be rigid.

Reed beds are fully parameterized based on the observations at the Romanian field sites, the drag coefficient is chosen lower than 1 but higher than the 0.19 used for salt marshes to account for the greater rigidity of reeds.

The properties of willows have been measured in two projects of Deltares (unpublished) along rivers in the Netherlands. For this vegetation type, the drag coefficient is chosen equal to that of mangroves, for the same reason of missing observations.

The calculated wave attenuation is very sensitive to the value of Cd. The field data generated in the FAST project has allowed an improved representation of the Cd for the species communities existing at FAST field sites. Over time, field data from additional sites and species communities will further enhance the quality of parameter estimations and associated model simulations. The need for this research can be related to implementation of advanced MI-SAFE services to new study sites.

3.5.2 Required crest height modelling

Solely assessing wave attenuation over a vegetated foreshore does not provide sufficient information about hazard -let alone risk- reduction. In reality, waves and water levels combined with characteristics of a levee (if existing) produce the total flood hazard. The required crest height of such levees therefore is strongly related to combined water level and wave height at the foot of the levee. An important failure mechanism happens when water flowing over the levee ('overtopping') resulting from wave run-up erodes the landward slope (Figure 3.12), thus threatening the geotechnical stability of the levee, as it reaches high velocities rushing down that slope. As vegetation on a foreshore typically gives lower waves at the levee foot, the required crest

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height can be lower too, which means that the same level of flood risk reduction can be achieved at lower costs with respect to maintaining a constant maximum overtopping volume level.

Figure 3.12 Failure of the inner slope of a levee as a result of a high overtopping discharge.

The calculation of required crest height (Rc) is based on empirical formulations described in Eurotop (Pullen et al., 2007). These relations form the basis of the official method for establishing required crest heights for levee designs and assessments in the Netherlands and other European countries. The Eurotop guidelines are the synthesis of a large number of experimental tests with varying levee geometries and hydraulic conditions that encompass most common levee designs. For a global analysis a different approach is required as in many places no coastal defence structures are present, or, if they are present, often properties of these structures are not known. Consequently, to be able to translate wave attenuation over a foreshore to a reduction of required crest height, several assumptions need to be made. First an allowed overtopping discharge needs to be chosen and second a standard schematisation of levee geometry for local hydraulic conditions needs to be assumed.

The allowed overtopping discharge (q) depends on the quality of the material of the levee, the resistance of the top layer and the incline of the inner slope. For example, good quality clay levees can withstand higher overtopping discharges than levees made of looser materials. Likewise, dense grass covers in good condition are more resistant than bare soils, but less resistant than asphalt cover layers. Steep slopes are less robust than gentle inclines because the water rushes down more rapidly and because of their inherently lower geotechnical stability. The allowed overtopping discharge is also related to duration of a design event (storm) as the deterioration of the inner slope is a time-dependent process. Here, we disregard the aspect of time is because of a lack of information on storm duration and to avoid a false sense of accuracy of the results. Experiments in large flumes and in the field have demonstrated the most resistant levees with good grass covers remain functional at overtopping discharges well above q=0.01 m3/s/m (Van der Meer et al., 2009). These are well-maintained levees in rich countries with vast engineering experience, so it seems unlikely that this is a representative value for global applications. A conservative choice of q=0.001 $m^3/s/m$ (Van der Meer et al., 2009) is more representative of simple earthen levees.

Given the lack of information on global levee properties, the calculations of required crest height in the MI-SAFE viewer are based on the (conservative) assumption that most levees have a basic configuration of a 1:3 outer slope without a berm and without substantial roughness or crest elements. For the design parameters at the toe of the levee, MI-SAFE calculates the wave height and water level (Figure 3.13) for the actual situations and a situation with an unvegetated foreshore. Subsequently, the MI-SAFE viewer uses these design parameters to compute the required crest height (relative to the still water level h) for both situations.

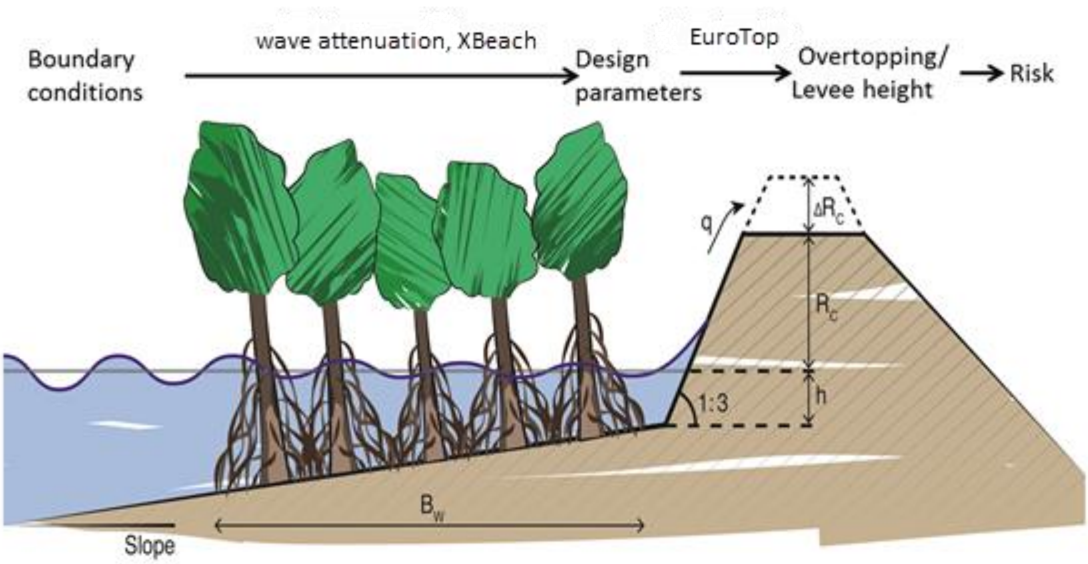

Figure 3.13. From boundary conditions to required crest height (with Bw: width of vegetation field, h: still water level, Rc: crest height, q: overtopping discharge) (adapted from thesis M. Janssen 2016).

4 The value of FAST

In this chapter we establish the value of the MI-SAFE package for the users. First some definitions.

What is included in the MI-SAFE package. This name groups all products and services generated and offered by MI-SAFE, including:

- Products
  - MI-SAFE online viewer (Educational and Expert);
  - The existing map data layers produced within the FAST project and available online
  - The model database with prepared results used for viewing
  - The algorithms produced to generate the maplayers
  - The open source XBEACH-Vegetation model
  - The Delft Dashboard with FAST map layer coupling
- Services
  - Updates of existing or creation of new datalayers that can be produced on request (Advanced),
  - The open source modelling using XBeach and Delft Dashboard (Advanced)
  - Access to the expertise for advice and consultancy (Advanced).
  - Access to community and related community services for training

4.1 Why was the MI-SAFE package developed?

Verifiable demonstration of potential of nature based flood defense solutions is lacking and it is clear that flood protection engineers need trusted and practical tools that provide them with the desired quantitative information on key flood hazard parameters. The FAST project has developed a package of services (MI-SAFE; http://www.fast-spaceproject.eu/index.php/services) to help meet this requirement, providing a range of data, information, and practical products and services that demonstrate how coastal vegetation can contribute to meet flood risk challenges.

4.2 Unique services

Our focus is to deliver smart services that will allow you to include ecosystem-engineering concepts into coastal protection (MI-SAFE package).

The main vehicle for demonstrating our services is a **user-friendly online viewer** (MI-SAFE viewer), where linkages between biological and morphological features of foreshores and floodplains are automated to predict potential requirements for flood safety infrastructure. This tool is based on the principles of nature based flood defence and gives you access to global open source data and model predictions, as well as local information for a series of case studies.

Our services are unique because they are:

- A combination of worldwide coastal coverage and high-resolution local analysis;
- In many areas of the world providing flood hazard related parameters that no other source can deliver;
- Based on transparent and verifiable scientific insights;

- Providing automated coupling of Earth Observation, water level, wave and vegetation modelling;
- Based on Open Geospatial Consortium (OGC) data streams – to be used with your own system, with free access and in standard formats;
- Built with Open Source tools - adaptable to your own tool chain;
- Supported by the Open Earth open source and free software community;
- Made for and with end users, thus catering to your specific needs.

4.3 MI-SAFE package

The MI-SAFE package includes a set of products and services.

The MI-SAFE viewer is designed to quickly and efficiently evaluate wave transformation over a foreshore. With this viewer, the user can click on any foreshore, automatically generating a transect over the upper foreshore that is translated into a quick assessment of slope and vegetation presence and into an estimate of the expected wave attenuation and crest height reduction (with uncertainty bands around a central value), depending on elevation, hydraulic boundary conditions and type of vegetation present (these are our 'Educational services'). For specific case study sites, the MI-SAFE viewer offers results calibrated and validated with higher quality and resolution (our 'Expert services').

To generate this information, FAST has gathered, reclassified or produced open format layers of information on elevation (topography and bathymetry), vegetation, and water and wave statistics; using Earth Observation resources (e.g. Sentinel satellite images), but also data collected in situ by the FAST consortium. These layers together with the intensive scientific field work that underpins FAST have been used to establish relationships between elevation and vegetation properties and water level and wave dynamics. Those relationships have been used to calibrate the open software model XBeach and thus to estimate the effects of foreshore vegetation on wave attenuation and dike overtopping.

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Figure 4.1. Summary of the MI-SAFE package with the MI-SAFE viewer as the key element used to access the Educational and Expert (green) as well as the Advanced services (blue).

The MI-SAFE viewer does not only show the potential effects of foreshore vegetation on wave attenuation, but also visualizes and gives access to open data layers (Educational services) and more specific regional/local scale data (case studies, Expert services). In addition, the MI-SAFE package offers opportunities for generating tailor-made solutions for users with natural-based coastal defence issues (Advanced services, see Figure 4.1).

4.4 MI-SAFE services and advice

The MI-SAFE services help engineering companies, governments, research institutes, NGOs and other users understand how foreshores reduce flood risk on any given shore worldwide. This knowledge helps to reduce the cost of flood protection as well as assisting efforts towards a more wide-spread, successful restoration and conservation of coastal ecosystems.

The MI-SAFE package is linked to existing open source data platforms and tools such as:

- Delft Software Days
- Deltares OSS community: http://oss.deltares.nl/
- XBeach modelling community: https://oss.deltares.nl/web/xbeach/
- Delft Dashboard: https://oss.deltares.nl/web/delft3d/general/-/message_boards?_19_mbCategoryId=410221

The MI-SAFE services are accessible through the MI-SAFE viewer and are made up of three key components:

1. **Open Geospatial Consortium (OGC) data streams**. This service is accessible via the MI-SAFE viewer and available via Catalogue Web Service (CWS) (Educational and Expert

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services), similar products can be generated by the FAST consortium on demand (Advanced services).
    a. Elevation (bathymetry and topography)
    b. Vegetation (presence, leaf-area-index, types)
    c. Wave and water level statistics (Hs, tidal range)
2. **Open Source Modelling**. This service is accessible via the MI-SAFE viewer (Educational (global scale) and Expert services (FAST study sites)), this service also includes calibration/validation for new sites and the modelling of new processes on demand (Advanced services).
    a. XBeach with vegetation for coastal, delta and riparian regions. Calibrated and validated by FAST for study sites.
    b. Flexible integration using OGC data streams (inputs and outputs). Built into Delft Dashboard - easy connection to Delft3D, LISFLOOD, and many other Open software models also built into Delft Dashboard.
    c. Open data and open source based on Open Earth conventions
3. **Advanced services**. To access to these services see the last section of this document. For end-users with specific issues on nature-based coastal defence, MI-SAFE offers Advanced services to provide tailor-made solutions.
    a. Generation of new/improved information (see above).
    b. Development of new model functionalities, calibration and validation (see above).
    c. Consultancy, training and support. MI-SAFE offers services of consultancy, training and/or support on data collection, setting up EO workflows, tuning models, OGC data streams or large-scale deployments.

4.5 MI-SAFE Educational service

For sites different to FAST study cases, the MI-SAFE viewer uses online global maps of water depth, elevation, and vegetation coverage derived from space-borne sensors, and with wave and storm surge conditions derived from global ocean models.

The MI-SAFE Educational service (see Figure 4.2) provides answers to questions about wave attenuation and crest height reduction over the foreshore, displaying the wave transformation along the actual profile and providing detailed context maps. This output is generated from global open data layers, limiting quality and resolution of the outputs. The MI-SAFE viewer provides users with easy access to the global open data layers. The main value of this service is that it offers a first indication of the presence and potential flood risk reducing effects of foreshores anywhere across the globe, including data scarce areas. The purpose of this service is to giving a preliminary evaluation of areas where foreshore vegetation may be contributing to coastal defence.

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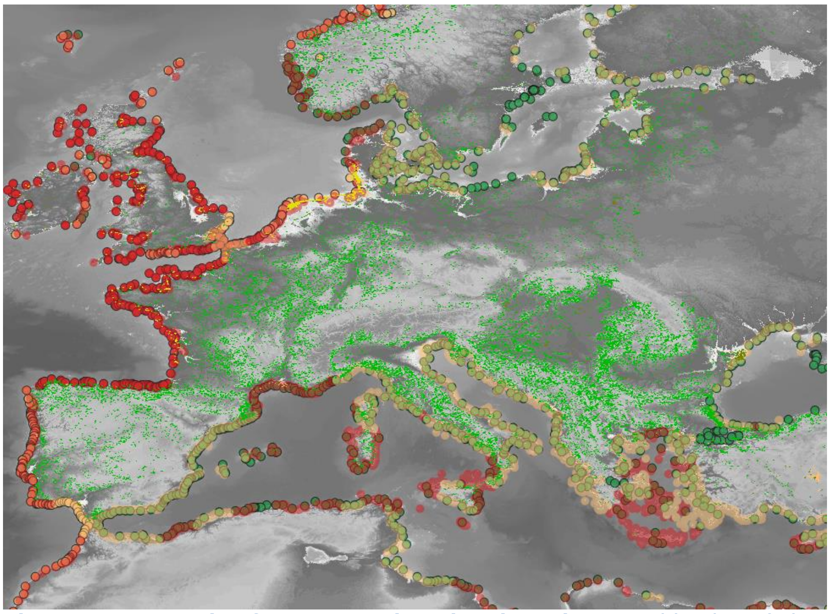

Figure 4.2. Example of MI-SAFE Educational service. Combination of elevation, tidal range, wave height and vegetation presence layers to estimate areas where foreshore vegetation has a potential contribution to reduce flood risk in Europe. All these layers are available via the Global Base maps of the MI-SAFE viewer at the Catalogue Web Service (CWS).

4.6 MI-SAFE Expert service

For FAST study sites, the FAST consortium calibrated and validated open data layers and XBeach with detailed local information on vegetation, bathymetry and waves (case study data). For FAST study sites, the MI-SAFE Expert mode uses the same storm conditions as the Educational version, but provides more details on underlying parameters, generating higher quality and resolution outputs (Figure 4.3).

The FAST consortium has implemented procedures based on INSPIRE metadata conventions. An active open source community will be ready for any questions related to the MI-SAFE viewer. This is linked to the facilities provided by Deltares and the training provided during the international Delft Software Days and, within the FAST countries, by national contacts who are familiar with the viewer and able to support its use.

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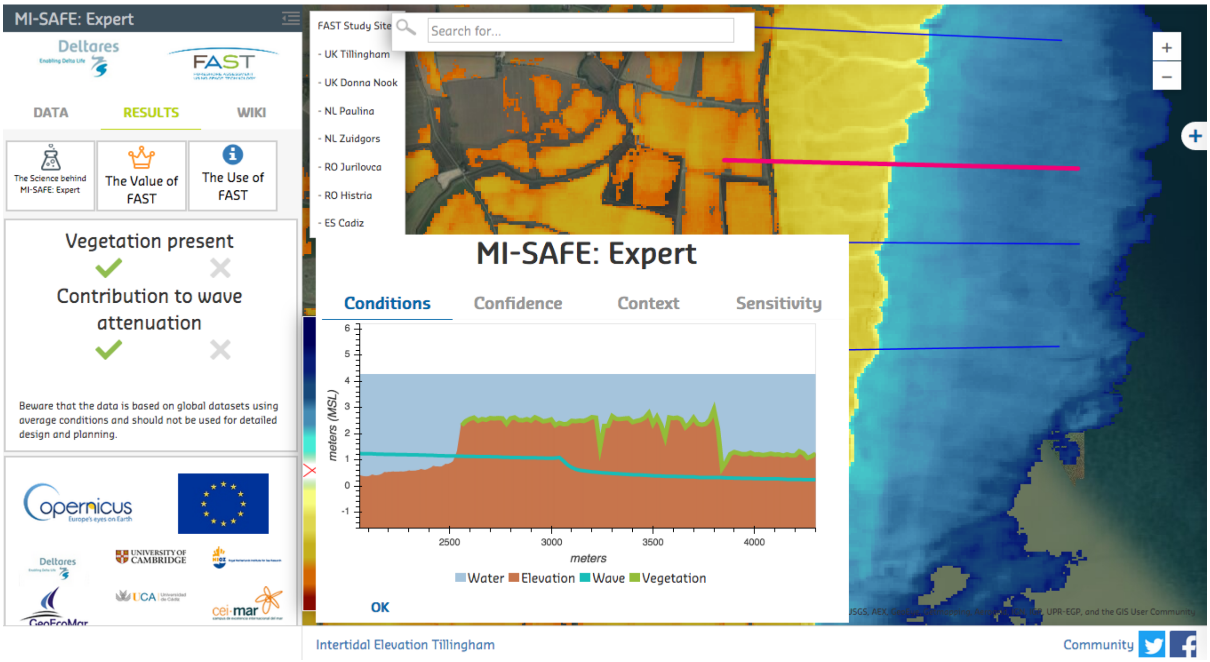

Figure 4.3. Screen shot of MI-SAFE viewer showing an example of Expert services for one FAST study site: Tillingham saltmarsh (UK).

4.7 MI-SAFE Advanced advisory services

For end-users with specific issues related to nature-based coastal defence or a specific site application, MI-SAFE offers advanced advisory services to provide tailor-made solutions. These services are tailored to individual users and include:

- Generation of new/improved information for a particular application/site. This could include in situ and remote (Earth Observation) data collection, processing and reporting.
    - Elevation data acquired by dGPS, UAVs, air/ground Lidar, or EO.
    - Vegetation data: field surveys, UAVs, EO and trend analysis.
    - Wave attenuation data: field measurements, long-term deployments.
    - Sediment dynamics data: field measurements and long term EO.
- Development of new model functionalities, calibration and validation.
    - Generation of new algorithms and data fusion, calibration and validation of model outputs for a specific or for different regions.
- Consultancy, training and support.
    - On data collection, setting up EO workflows, tuning models, OGC data streams or large-scale deployments.

As an example of an advanced advisory service, FAST has combined products and services with products and services generated by the EU project RISC-KIT to estimate the risk of overtopping (XBeach, FAST) and the corresponding flooding (LISFLOOD, RISC-KIT) for our Tillingham study site (UK) (Figure 4.4).

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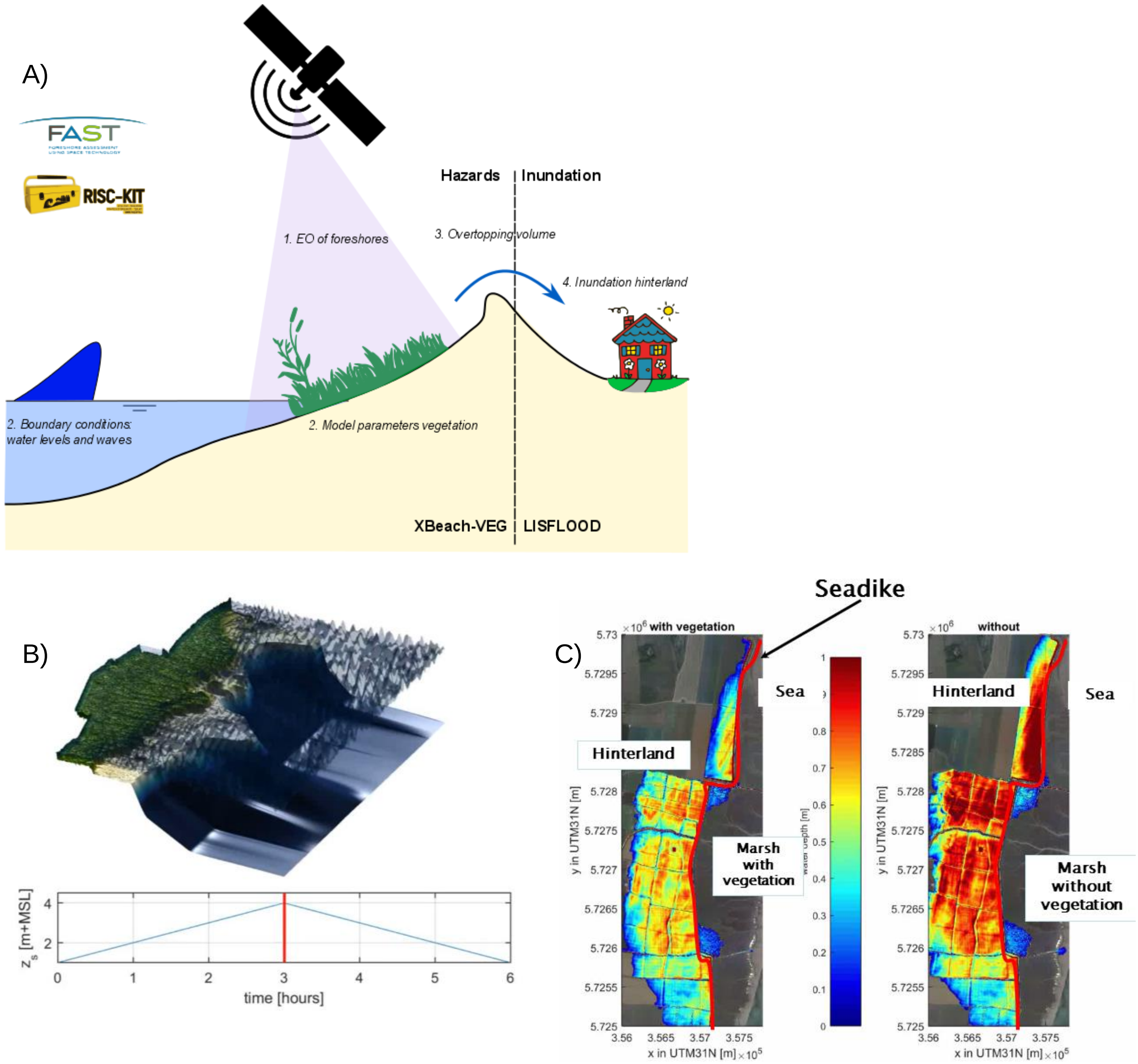

Figure 4.4. A) Combination of FAST (XBeach-VEG) and RISC-KIT (LISFLOOD) elements used to generate an advanced service on overtopping and inundation due to the impact of a large storm on a vegetated foreshore. B) XBeach 3D non-hydrostatic model of impact of a large storm at Tillingham saltmarsh (UK). C) LISFLOOD simulation inundation of impact of a large storm at Tillingham saltmarsh (UK).

4.8 Summary of the MI-SAFE package

The description of MI-SAFE, the means of accessing the information and the FAST expertise that is linked to the specific MI-SAFE components are summarized in Table 4.1.

Table 4.1. Summary of the MI-SAFE components, including a short description, access route to relevant data and FAST consortium expertise.

MI-SAFE service description	Product/Service	Access	FAST expertise
Bathymetry/topography OGC data			
Global	SRTM15+, SRTM30	WMS/WCS	MI-SAFE viewer 
Global intertidal elevations	FAST-IE		
Regional/Local topography	EMODNet	MI-SAFE Advanced	Deltares, NIOZ, UCA
Regional/Local topography: Land (10 - 1 km^2)	Lidar, UAV, Ground-lidar, dGPS4		University of Cambridge, NIOZ, UCA
Vegetation OGC data			
Global	FAST-GLC2009_VEG	WMS/WCS	MI-SAFE viewer 
Europe	FAST-CLC2012_VEG		
Global/coast	FAST-Veg_GEE		
Local (10 - 1 km^2)	FAST-NDVI, FASTLAI, UAV, Ground-Spectrometry, Ground-Sampling	MI-SAFE Advanced	NIOZ, UCA, University of Cambridge, GeoEcoMar
Water level and wave statistics			
Global/Coast water statistics	ERA-interim	WMS/WFS	MI-SAFE viewer 
Regional/Local near-shore water modelled statistics	FAST-SWAN, FAST-XBEACH-VEG (1D and 2D)	MI-SAFE Advanced	Deltares, UCA
Local shallow water measured statistics	Ground-Measurements		University of Cambridge
OS Modeling			
Open Source Modeling	XBeach with vegetation, Flexible integration using OGC data streams	OpenEarth / MI-SAFE Advanced	Deltares

MI-SAFE Advanced services may include: Data collection, review, quality check and support. Available on two formats: Consultancy and/or training

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5 Development of Service Level Agreements

5.1 SLA 1: Services and products of MI-SAFE Educational[1] (Awareness raising modality)

The Educational modality of the MI-SAFE package includes the following services and products which are all accessible via MI-SAFE viewer:

MI-SAFE service description	Product/service
Bathymetry/topography OGC data	
Global	**SRTM 15+, SRTM 30+**
Global intertidal elevations	**FAST-IE**
Vegetation OGC data	
Global, Europe	**FAST-GLC2009_VEG** **FAST-CLC2012_VEG**
Global/coast	**FAST-Veg. GEE**
Water level and wave statistics	
Global/coast water statistics	**ERA-interim**
OS Modeling	
Open Source Modeling	**XBeach with vegetation** **Flexible integration using OGC streams**

MI-SAFE Educational services:

- Presenting EO data and relevant data from open source global sources in web viewer using an easy-to-use on-line viewer (MI-SAFE viewer).
- Explaining the knowledge rules generated by the FAST project (the science behind MI-SAFE).
- Creating and presenting FAST outputs in an online viewer using knowledge rules and numerical analysis at global scale (i.e. providing data in data poor areas but with high uncertainties)

5.1.1 Pricing

The services and products of MI-SAFE Educational are available freely through the MI-SAFE viewer. Information on updates, training opportunities etcetera can be obtained by joining the FAST online community. Additional services such as training and maintenance can be requested through the MI-SAFE consortium (http://www.fast-space-project.eu/index.php/team).

[1] Deltares software products disclaimer applies to all MI-SAFE products and services.

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5.2 SLA 2: MI-SAFE Expert level (Assessment modality, High quality study sites)[2]

The Expert level of the MI-SAFE package includes the Educational level and the following services and products that are accessible through MI-SAFE viewer:

MI-SAFE service description	Product/service
	MI-SAFE Educational modality
Bathymetry/topography OGC data	
Regional/local topography	**EMODNet +**
Regional/local topography Land in FAST case study areas	**Lidar, UAV, Ground-Lidar, dGPS4**
Vegetation OGC data	
Local (10-1 km^2) in FAST case study areas	**FAST-NDVI, FAST-LAI, UAV, ground-spectrometry, ground-sampling**
Water level and wave statistics	
Regional/local near-shore water modelled statistics	**FAST-SWAN, FAST-XBeach-VEG (1D and 2D)**
Local shallow water measured statistics in FAST case study areas	**Ground-Measurements**

MI-SAFE Expert services:

- Downloading the Sentinel data and retrieving value added products from Sentinel in agreement with use conditions specified by the MI-SAFE consortium and the ESA.
- Sentinel EO derived products updates in agreement with use conditions specified by ESA.
- Knowledge rules themselves (expressed in the algorithms and linked to knowledge producers).
- FAST project generated info in web viewer with increased spatial resolution for regional and local studies and increased information on storm surge impacts .
- Downloading maps to local system (in NETCDF) or otherwise (this is not automated yet).
- Join Community of Practice (CoP) that promotes the further professionalization of “eco engineers” by promoting and facilitating the exchange between (civil) engineers and ‘green infrastructure/ nature experts.

5.2.1 Pricing

The services and products of the Expert mode are available freely through the MI-SAFE viewer. Additional services such as training and maintenance can be requested through the MI-SAFE community, the consortium (http://www.fast-space-project.eu/index.php/team) and are available at events such as the Delft Software Days (http://www.dsd-int.nl/2017/) to MI-SAFE Expert users for the following price:

MI-SAFE Expert training	Unit
Attendance at MI-SAFE course at Delft Software Days (including lunch)	8 hours

[2] Deltares software products disclaimer applies to all MI-SAFE products and services.

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Understanding EO data lecture	8 hours
First glimpse of EO product	4 hours
Expert training of XBeach model and Delft Dashboard	4 hours
Certificate of course attendance	
Total price of package	**€ 950**

5.3 SLA 3: MI-SAFE Advanced level (Intervention and evaluation modality)[3]

The Advanced level of the MI-SAFE package offers, on request, the services and products developed under the Expert level but validated, calibrated or developed for new study sites.

Additionally, MI-SAFE Advanced also offers further options for services to be discussed through consultancy by the FAST team of experts, including:

MI-SAFE service description	Product/service
Software and service development	Building new functionalities (i.e. seasonality, scenario analysis, specific abiotic or biotic parameters) Buying datasets
Vegetation data	Protocols for ground truthing (these can be customized to local needs) Collection and processing of satellite data imagery Validation of EO data (ground truthing)
Maintenance	Offsite back-up and disaster recovery services including repair/replacement of equipment IT support (debugging, maintenance, etc.)
Consultancy	Advice from FAST experts (problem analysis, review, quality check and support) Training services

5.3.1 Pricing

The Advanced package can be customised on demand but includes at least the following services:

MI-SAFE Advanced training	Unit
Training intake	4 hours
Development of course material	8 hours
Collecting relevant information for specific application	16 hours
Applying XBeach model	16 hours
Creating first EO product with MI-SAFE package	16 hours
Linking MI-SAFE to existing data infrastructure	8 hours
Total price of package	**€ 11.500**

[3] Deltares software products disclaimer applies to all MI-SAFE products and services.

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MI-SAFE Advanced consultancy for specific location	Unit
Consultancy intake	8 hours
- Collecting ground truthing data in the field (bathymetry and topography mapping, vegetation mapping, hydraulic conditions)[4]	pm
- XBeach modelling for specific surge conditions	pm
- First EO product	16 hours
Maintenance (organizing data server, back-up and recovery services)	8 hours
Additional services	
- Building new functionalities	pm
- Data service (including buying, validation and analysis)	pm
- Link to other relevant Disaster Risk Reduction models	pm
- Other	pm
Total price of package	**€ 7500+pm**

These services are valid for 12 months and can be expanded on request. Prices for building new functionalities, EO data/model validation, data service (including buying data, validation and data analysis) and modelling are available on request.

[4] Excluding costs for equipment

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6 How to get in contact with the FAST consortium

To request advanced consultancy services, or to get support for the Educational and Expert services, contact the FAST consortium via the FAST web page, the MI-SAFE viewer, the FAST twitter account (@FP7FAST), the FAST Facebook page (FastSpaceProject) or MI-SAFE twitter account (@MISAFE_services). Additionally, you can contact the FAST consortium via any of our regional contacts.

Deltares
(PROJECT LEADER)

Mindert de Vries
mindert.devries@deltares.nl
Tel. +31(0)6 2348 0876

Deltares is the Dutch institute for applied research and development on issues related to water and soil management in delta areas. The primary task of Deltares is bringing together science and application.

UCam
University of Cambridge

Iris Möller
iris.moeller@geog.cam.ac.uk
Tel. +44 (0)1223 333353

The Cambridge Coastal Research Unit (CCRU), University of Cambridge, carries out fundamental research on coastal, estuarine and nearshore processes, landforms and ecosystems, with a particular focus on flood and erosion risk reduction in the coastal zone.

GeoEcoMar
National Institute for Marine Geology and Geo-Ecology

Adrian Stanica
astanica@geoecomar.ro
Tel. +40 21 2094986

GeoEcoMar is a Romanian Research Institute with excellent expertise in geology, geoecology and geophysics, focusing on the Danube – Danube Delta – Black Sea macrosystem in particular and aquatic environments in general.

NIOZ
Royal Netherlands Institute for Sea Research

Daphne van der Wal
daphne.van.der.Wal@nioz.nl
Tel. +31(0)113 577300

Royal Netherlands Institute for Sea Research, NIOZ, is the Dutch national marine science institute. Our mission is to gain and communicate scientific knowledge on the world's oceans, seas and estuaries for the understanding and sustainability of our planet. NIOZ facilitates and supports fundamental as well as applied marine research and education in the Netherlands and Europe.

UCA
Universidad de Cádiz

Gloria Peralta
gloria.peralta@uca.es
Tel. +34 956 016 428

UCA is the leader of the "International Campus of Excellence in Marine Science"(CEI·MAR), bringing together universities, research institutes, companies and social agents in Spain, Portugal and Morocco, forming a collaboration platform between scientists and end-users.

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Annex I: Delft Software Days poster, joint with RISC-KIT

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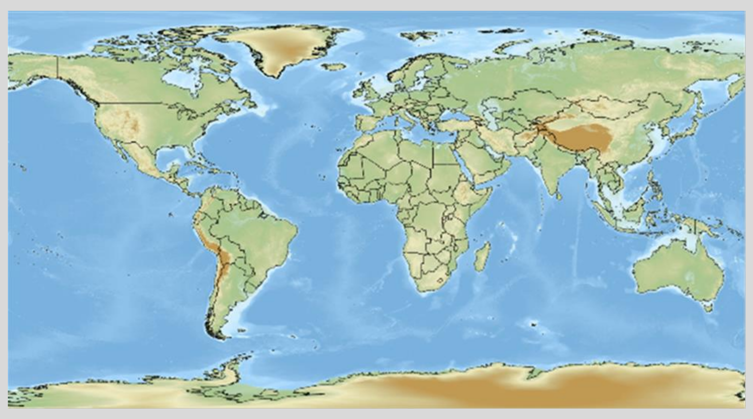
FAST
FORESHORE ASSESSMENT USING SPACE TECHNOLOGY

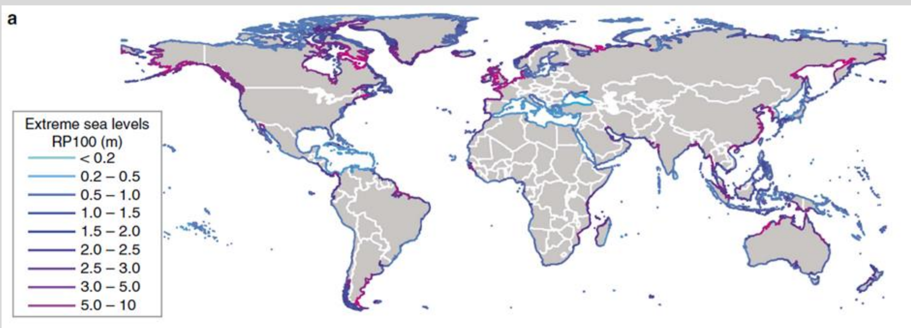
Aim:
FAST helps engineering companies, governments, research institutes, NGOs and other users understand how vegetated foreshores reduce coastal flood risk on any given coast worldwide. This knowledge may help to reduce the cost of flood protection as well as may deliver inputs to a more wide-spread, successful restoration and conservation of coastal ecosystems.

Services:
- EO based maps of elevation and vegetation, resolution 10x10m
- MI-SAFE tool:
  -reduction of wave height and required crest height by vegetation on foreshore
  -Educational, Expert and Advanced modes

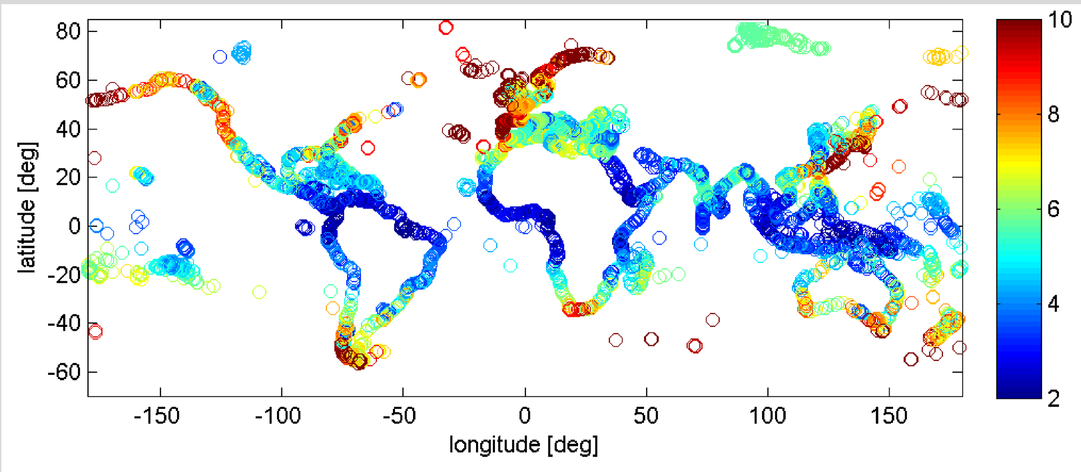
MI-SAFE Educational: Global data



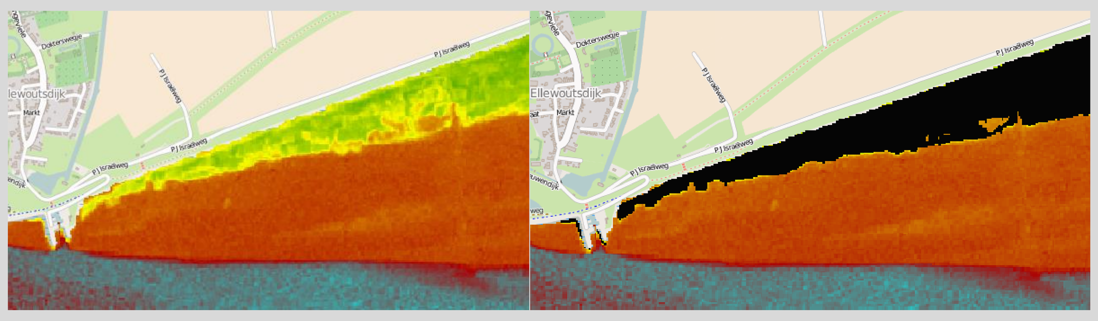
Global bathymetry and topography from SRTM and GEBCO.



Global extreme water levels (tide + surge) for a return period of 100 years. From Muis et al. (2016).



Global significant wave heights and periods from ERA-Interim.



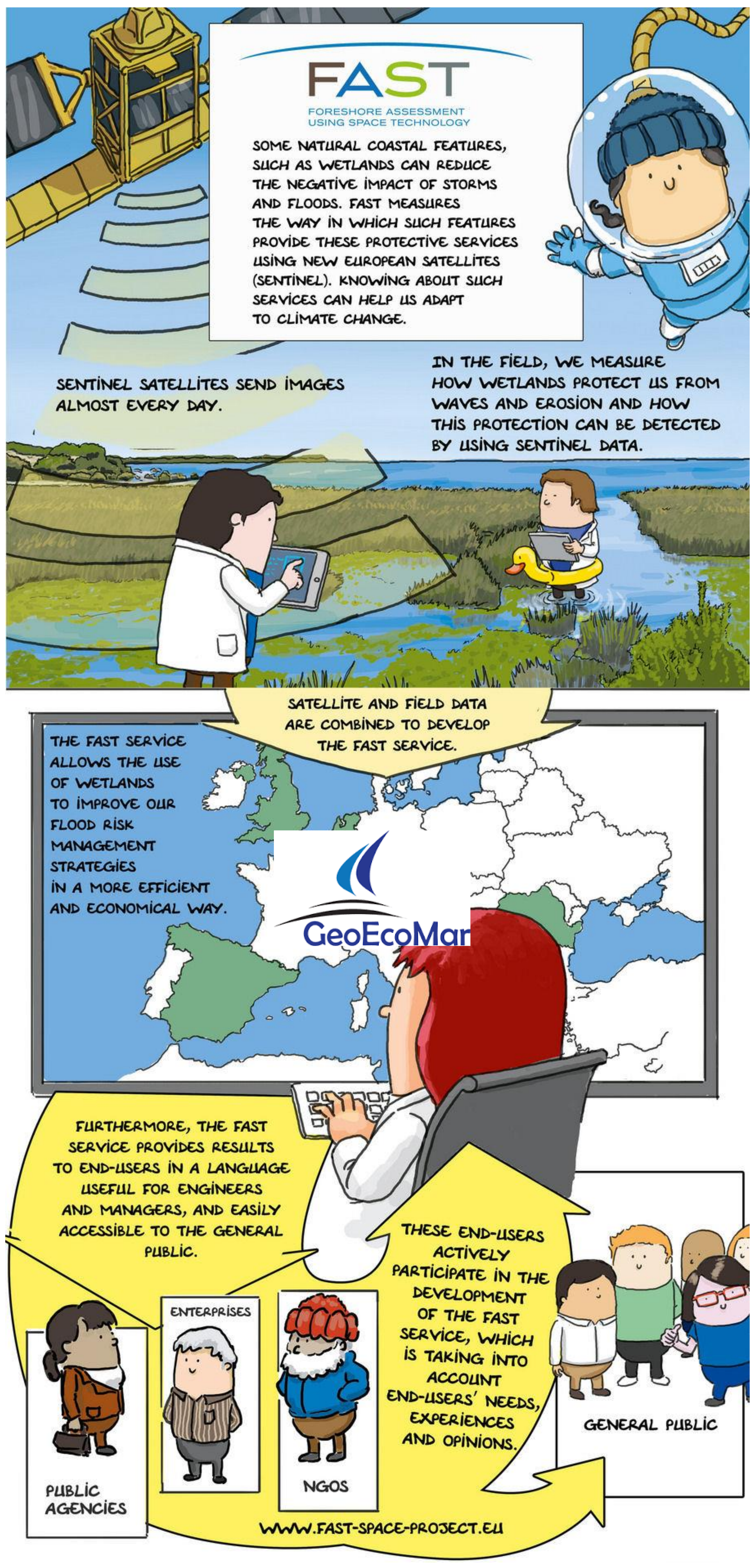
Global vegetation presence derived from NDVI from Landsat/Sentinel EO data. Left: NDVI at Zuidgors site (NL). Right: vegetation presence.

global answer
quick scan

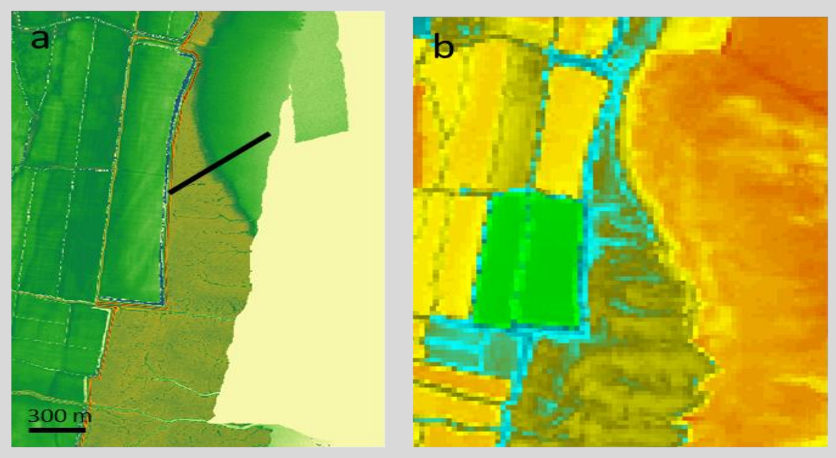
Vegetation present ✓ ✗

Contribution to wave attenuation ✓ ✗

Beware that the data is based on global datasets using average conditions and should not be used for detailed design and planning.

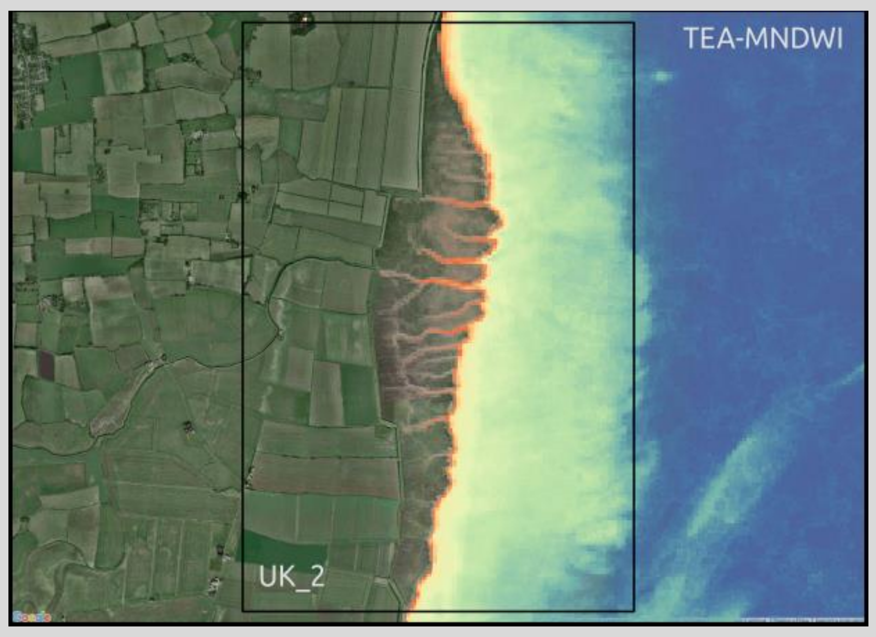


MI-SAFE Expert: Detailed data



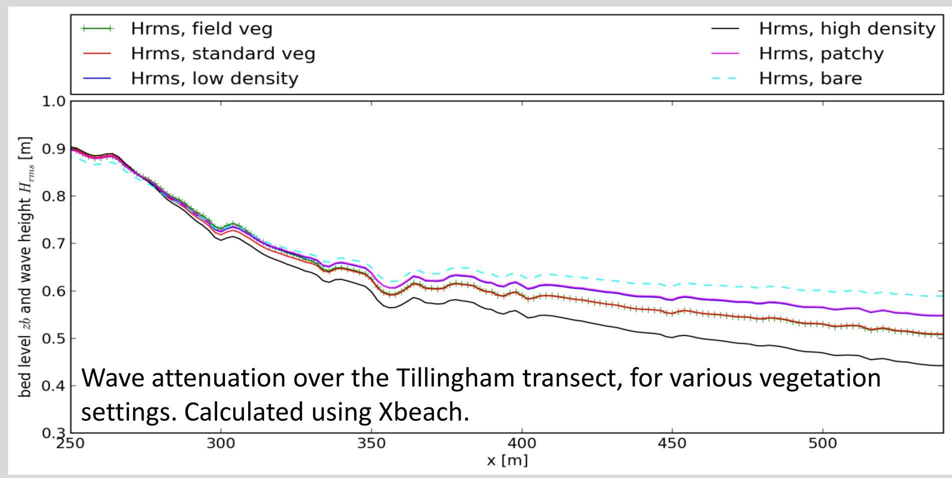
Overview of the Tillingham field site (UK). a) The observation transect on a cut-out of the detailed (1m) DEM. b) The NDVI map.

Measurements of in-situ spectra and vegetation dimensions at Romanian field site to link spectral EO data to local vegetation properties.

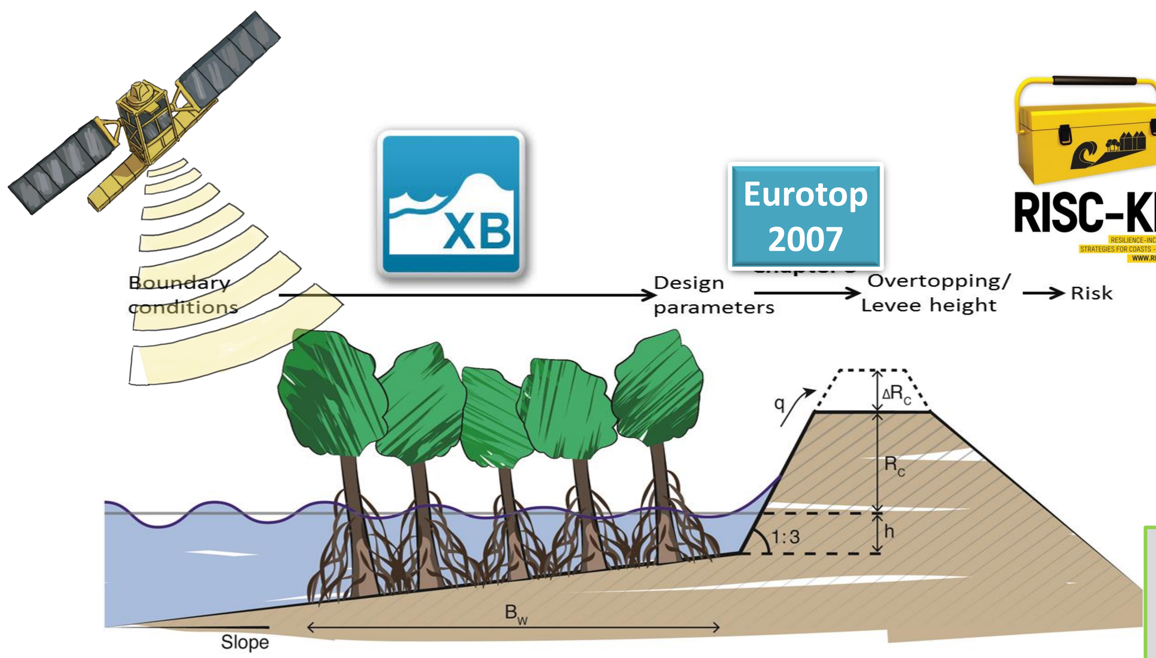


Time-ensemble average water indices for Tillingham (UK). Yellow to red represents reducing flooding frequency; a proxy for increasing elevation.

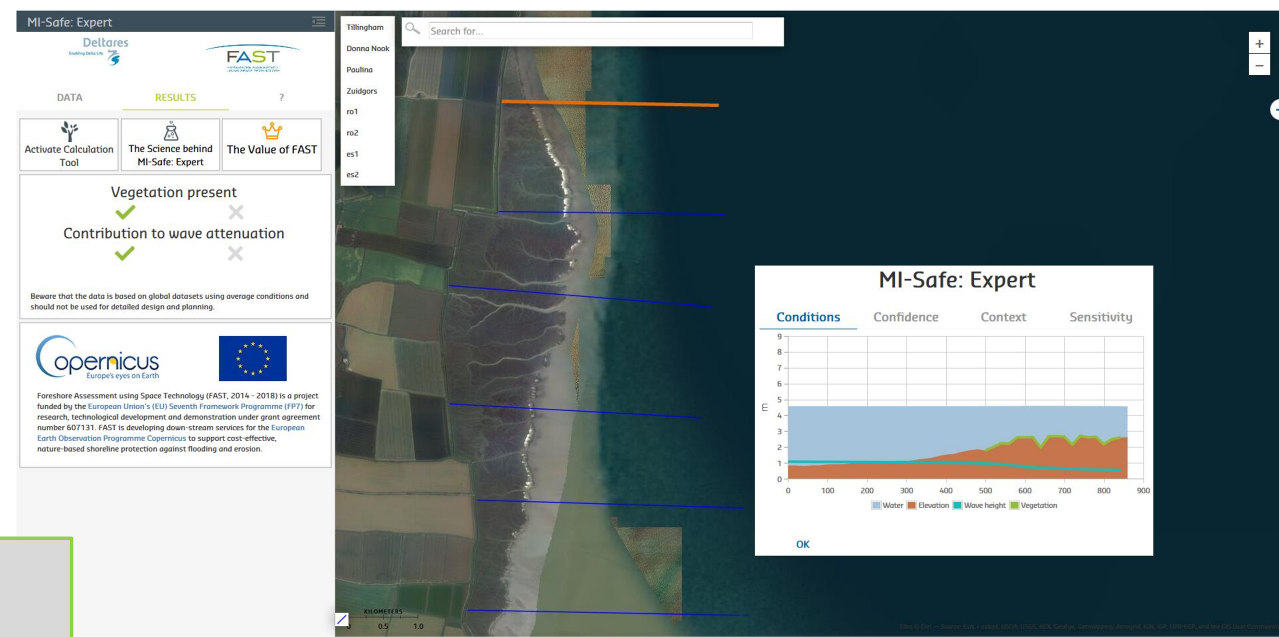
more confidence in answer
FAST field sites



Wave attenuation over the Tillingham transect, for various vegetation settings. Calculated using Xbeach.



The MI-SAFE workflow.



Screenshot of the MI-SAFE tool.

MI-SAFE Advanced: High-resolution tailor-made answer
for your site(s)

The advanced mode offers users the possibility of asking location specific questions about the impact of foreshores and floodplains of water levels and waves.

- What are the (seasonal) trends in the elevation, area or vegetation cover of a foreshore?
- How does a specific storm surge event impact a specific foreshore location?
- How does a foreshore precisely impact the flood safety, in relation to existing defenses (run-up, overtopping)?
- How does the foreshore respond to different climate change and sea level rise scenarios?
- How can foreshores be integrated in nature based solutions for flood risk reduction?

This mode adds:

- Time series of information for specific events;
- Particular probabilities of occurrence , local flood protection standards;
- Link to Disaster Risk Reduction activities, e.g. via RISC-KIT
- Facility to upload local data sets;
- Assistance by our experts and;
- Use of updated EO databases.

Vegetation cover	Return period					
	1/10 yrs		1/100 yrs		1/1000 yrs	
	H_s	R_c	H_s	R_c	H_s	R_c
Low vegetation density	5	8	6	10	7	12
Standard vegetation density	4	7	5	9	6	11
High vegetation density	3	6	4	8	5	10

Example

Significant wave height H_s (m) and required crest height R_c (m) for various vegetation covers and return periods of design conditions.

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Foreshore Assessment using Space Technology (FAST, 2014 - 2018) is a project funded by the European Union's (EU) Seventh Framework Programme (FP7) for research, technological development and demonstration under grant agreement number 607131. FAST is developing down-stream services for the European Earth Observation Programme Copernicus to support cost-effective, nature-based shoreline protection against flooding and erosion.

Annex II: Instruction video on the use of the MI-SAFE viewer

A video is created to give a quick overview of the functionality and the features of the MI-SAFE viewer.

How to access the video

For FAST it turned out to be very useful to use the wikipage approach and so enabling the partners to work on the same information in a user friendly environment. The OpenEarth Wiki is suited with functionality to host animations. The video showing the viewer can be best reached by the button The Use of MI-SAFE (Figure 0.1). This will redirect to a wiki page with a methodological video (Figure 0.2).

Figure 0.1. MI-SAFE button bar (componente 10 in Error! Reference source not found.**). The 'Use of MI-AFE' button redirects to the methodological video page.**

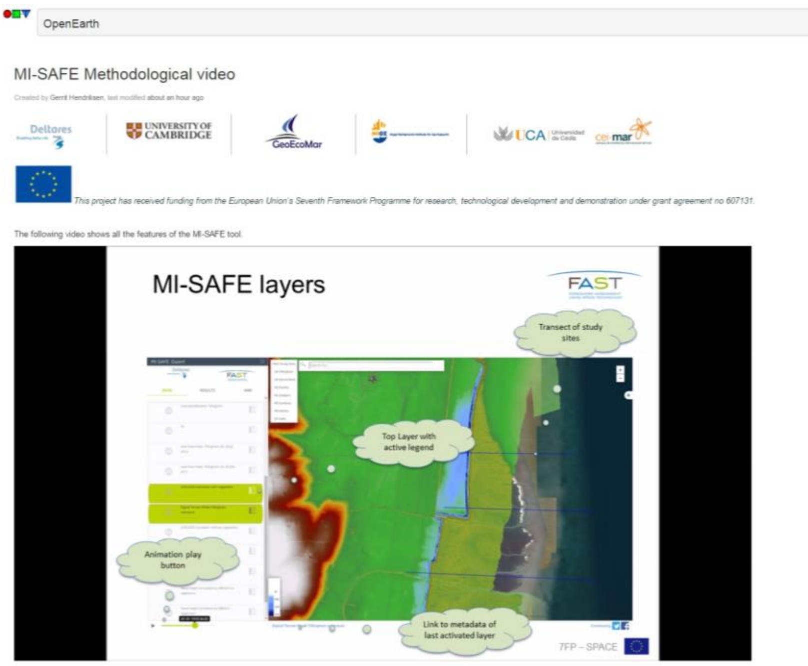

Figure 0.2 Screenshot of page where methodological video is available

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