FAST MI-SAFE PLATFORM: FORESHORE ASSESSMENT USING SPACE TECHNOLOGY

Joan Sala Calero[1], Gerrit Hendriksen[1], Jasper Dijkstra[1], Amrit Cado van der Lelij[1], Mindert de Vries[1], Rudie Ekkelenkamp[1], and Edward P. Morris[2]

[1] Deltares, Boussinesqweg. 1, 2629HV Delft, the Netherlands
[2] Universidad de Cádiz, 11510 Puerto Real, Spain

ABSTRACT

Foreshore Assessment using Space Technology [1] (FAST, 2014-2018, EU-FP7 607131) has created a platform for EU Earth Observation (EO) Programme Copernicus services, to support cost-effective, nature-based shoreline protection. Called "MI-SAFE", it is developed with Open Source (OS) Intelligent Geographical Information System (IGIS) components from the OpenEarth [2] stack, and interoperable OGC standards. Processing large volumes of EO data for global coastal vegetation and elevation products is done using the cloud native Google Earth Engine platform. These are intelligently combined with other layers to form the inputs to XBeach [3], an OS hydrodynamic model developed by Deltares, UNESCO-IHE and TU Delft. Access to data is via a web-based user interface with different resolutions and complexity (Educational and Expert modes), and a Catalogue Service for the Web (CSW). MI-SAFE is intended to be a sustainable contribution to coastal Nature-based Solutions, increasing both awareness and facilitating advanced modelling, within the engineering community.

Index Terms— OGC protocols, Maritime safety, Marine Information System, Copernicus, Earth Observation, OpenEarth, XBeach, INSPIRE, Google Earth Engine, Coast, Nature

1. INTRODUCTION

Marine foreshores are currently not included in water safety assessments and levee design. However, foreshores deliver several services, such as increasing sedimentation, reducing erosion and attenuating waves that mitigate flood risk by improving levee stability and lifetime. Including foreshores in levee design and safety assessments can result in considerable cost reductions for flood risk management.

The FAST (Foreshore Assessment using Space Technology) project has developed a platform (MI-SAFE) to provide key data for modelling foreshores; such as elevation, morphology, sediment and vegetation properties. This includes new products derived from the USGS Landsat and Copernicus Sentinel EO missions, and field measurements, such as wave attenuation and erosion/deposition suitable for calibration/validation activities. Using these, the OS XBeach model was adjusted to include vegetation (XBeach-VEG) at eight characteristic case-study sites across Europe (Spain, Romania, United Kingdom, and the Netherlands).

Relationships between foreshore properties and wave attenuation were used for extensive XBeach-VEG simulations, which trained a Bayesian model; allowing rapid estimation of flood risk reduction for any observable combination of foreshore properties. User interaction with model results was facilitated by implementing a fully OS Intelligent GIS with a web viewer, extensive documentation, and a Catalogue Service for the Web (CSW). Results are presented in two modalities, focussing on 2 main user groups (Educational and Expert users).

2. EDUCATIONAL AND EXPERT MODES

The Educational mode gives a first indication of the presence, and potential flood risk reducing effects of foreshores. It uses a combination of available standard data products, such as global SRTM elevation, and new products, such as global intertidal elevation (section 4.1), and coastal vegetation presence (section 4.2), derived from processing large volumes of EO time-series data. Users can explore the contribution of vegetation to flood risk reduction, i.e., the results of the Bayesian model, at any one of 20000 profiles across the shorelines of the globe.

The Expert mode shows XBeach-VEG simulations made with high resolution data, and hydrodynamic boundary conditions for various future scenarios. At present this is mainly limited to the case-study sites; but should increase as more data is ingested. Providing a detailed indication of the effects of foreshores on wave attenuation, it also includes an example of a 2D XBeach-VEG simulation coupled with a flood model (LISFLOOD). It aims to show Expert users the potential of EO derived data products combined with OS modelling to contribute to the development of Nature-based Solutions for shoreline protection. Allowing engineers to optimally use the coastal foreshores existing ecological and landscape attributes to reduce costs.

The platform uses OS data structures, and OA data described following the INSPIRE metadata conventions. The web viewer is available at http://fast.openearth.eu, data layers are accessible at http://fast.openearth.eu/geonetwork/, and modelling support is available from the active XBeach community https://oss.deltares.nl/web/xbeach.

3. SYSTEM ARCHITECTURE

The multi-layered client-server architecture of the MI-SAFE platform can be subdivided in three main blocks (Presentation, Logic and Data) corresponding to a three-tier system application (Figure 1). The first layer handles user interaction with the web platform (an instance of Delta Data Viewer, DDV), whereas logic is handled by PyWPS services in the back-end. XBeach is used for across shore wave modelling. Raster data is stored and accessed by GeoServer and vectors by PostgreSQL/PostGIS. GeoNetwork is used to edit and serve metadata. Last but not least, the cloud native Google Earth Engine platform is used to transform large volumes of EO data into global coastal data products.

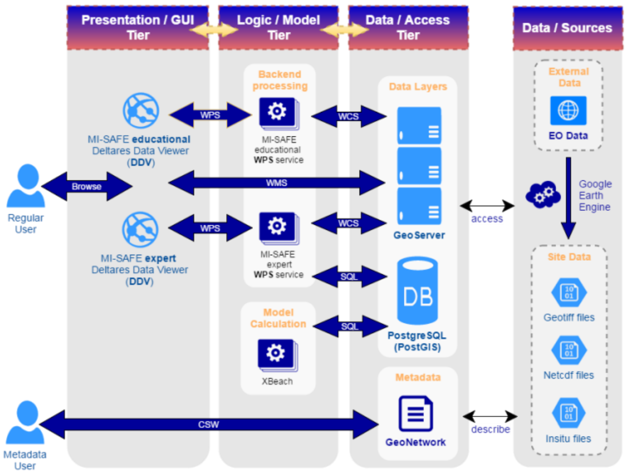

Figure 1. The multi-layered client-server architecture of the MI–SAFE platform.

3.1. Presentation Tier (Deltares Data Viewer)

The MI-SAFE platform uses a customized instance of the Deltares Data Viewer (DDV) based on OpenLayers, an OS GIS viewer from the OpenEarth stack (https://github.com/openearth). The viewer makes data requests via OGC WPS protocol to the back-end, which returns information to produce plots and reports. Visualization of data layers is via OGC WMS, with layer definitions harvested dynamically by querying the FAST GeoServer via GetCapabilities (WMS).

The structure of the viewer includes a canvas where maps are shown, a table of contents where layers can be toggled on or off, and a pop-up that provides visualization of the modelling output (Figure 2). User interaction includes selecting data layers, and clicking on a coastline to see model simulations. Coordinates of this point are sent to the Logic tier, and this initiates a search to find the nearest pre-defined coastline segment (within a buffer of 1 degree). Coordinates of the transect are sent back to the Presentation tier, and appear to the user as a 2 km long line perpendicular to the coast. Results for the transect are calculated in the Logic tier, returned, and graphically presented to the user as a 2D plot of the transect; designed to highlight vegetation presence, and potential contribution to wave attenuation. This includes contextual information such as the required crest height with and without vegetation and attenuation coefficients.

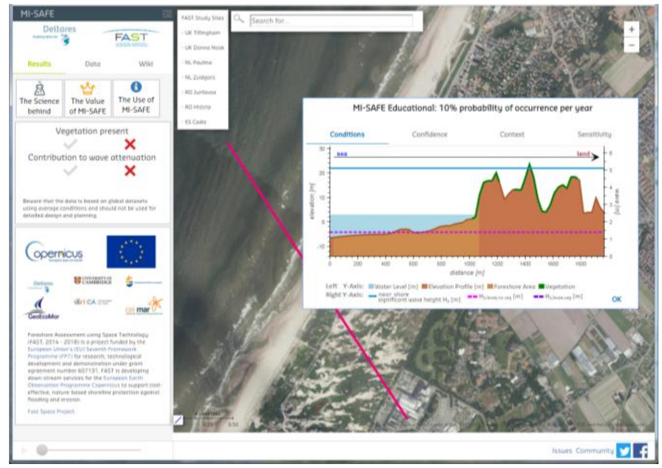

Figure. 2. The DDV web GIS interface showing a transect result.

3.2. Logic Tier (PyWPS and XBeach)

PyWPS is used to get, calculate, and return transect results to the Presentation tier. This Python implementation of the OGC WPS protocol makes use of owslib and GDAL libraries to retrieve data values via WCS from the data layers in the Data Access tier.

The initial input of a clicked coordinate on the web map starts the search for a pre-calculated expert transect. In case no data is available an on-the-fly educational transect is computed (Figure 3). For the selected location, hydraulic boundary conditions in the form of off-shore wave data and surge levels are extracted from the ERA-interim dataset and the Global Tide and Surge Model respectively. Those are translated to onshore conditions on fixed return periods. For the educational mode, this is only a storm event return period of 10 years (an event with a likelihood of 10% in any given year), whereas for the expert mode 1% and 0.1% likelihoods are also shown in the plot.

Topography and vegetation properties (presence, type, and at study sites Leaf Area Index, LAI) of the transect are potentially obtained from the Data tier at different resolutions, and from several sources that may overlap. Hence, a selection rule is used that gives priority to pixels covered by the highest resolution layers (with the implicit assumption that they are better quality). Where EO derived LAI values are not available, i.e., the Educational mode, a standard LAI value is assigned to each pixel based on it's type.

The matrix of variables (significant wave height, peak wave period, storm surge level, elevation, and LAI) returned from the Data tier can then be used to dynamically run XBeach-VEG simulation(s). However, depending on computing resources this may take some time, hence rapid access is provided by querying a pre-defined look-up table. This is derived from pre-calculated XBeach simulations (~

30 000) that represent the global range in variables, which were used to train a Bayesian model.

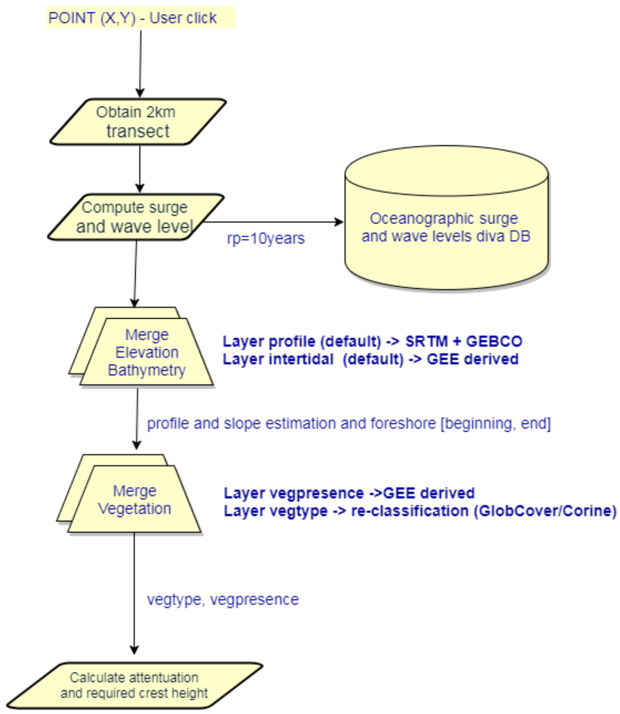

Figure 3. The MI-SAFE educational algorithm steps.

3.3. Data Tier (GeoNetwork, GeoServer, PostGIS)

For the Data tier 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; providing WMS access for visualization, and WCS for coverage queries. GeoNetwork is deployed as a catalogue solution for metadata editing, and a discovery interface through the CSW protocol. Vector outputs produced by XBeach simulations are stored in a PostGIS database that enables fast queries from the PyWPS instance.

4. DATA LAYERS

MI-SAFE uses a mix of global, regional, and local data sets to provide both the educational and expert modes. These can easily be updated as improvements are released. Presently the standard global layers include; bathymetry (GEBCO), topography (SRTM), land cover and vegetation type (CORINE + GLOBCOVER reclassification), wave and surge information (diva world wave periods), and coastlines (OpenStreetMap). Regional and local datasets include; combined elevation/bathymetry for the Netherlands (AHN combined with vaklodingen), and high-resolution Digital Elevation Models (DEM) and LAI at the study sites.

Early on in the conception of the platform the difficulties of matching global elevation/bathymetry, poor coverage in intertidal zones, and low resolution of global land cover maps, led us to develop two global datasets from high resolution EO data.

4.1. Global Intertidal Elevation

To improve the coverage in the gap between global bathymetry (GEBCO), and topography (SRTM) a global intertidal elevation map was derived using a combination of USGS Landsat and Copernicus Sentinel 2 images collected between 1997 and 2017.

Based on the traditional ‘waterline’ method [4, 5]; for each area-of-interest (AOI) on the coast, surface water was identified (using indices and classification) in a number of images (median of 317 images per AOI) with different tidal elevations. Composite, time-ensemble average (TEA) images of the probability of inundation were created, which were converted to intertidal elevation maps.

As assigning water levels to each image was not feasible at the global level, we developed a novel technique to transform TEA images of normalised difference spectral indices (NDSI) that represent water (here the NDSI of SWIR1 and Green bands), to elevation. Rather than segment every image into land-water, we normalised TEA-NDSI images by the spatially-averaged values of regions identified (using global elevation data sets) as land and water, respectively. This yielded a single image per AOI that represents inundation probability, and for each pixel in the intertidal zone, we assume that this represents the long-term average of tidal inundation.

As this inundation probability is derived from a collection of images that span a time period 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 equivalent to local mean sea level (LMSL).

Global tidal statistics (LAT/HAT, 2005 to 2025) for each AOI were derived from the Global Tide and Surge Model (GTSM) [6], and used to rescale inundation probability images, giving an estimation of mean intertidal elevation (m, LMSL) in the period 1997 and 2017.

The process was carried out on ~ 20000 AOIs covering the global coast (defined using Open Street Map tiles) in Google Earth Engine, and took ~ 60 days. Validation of the predicted versus observed elevation at the case study sites, and other regions with quality intertidal elevation data suggested Root Mean Square Error (RMSE) values ranging between 0.3 and 1 m (Figure 3). Nevertheless, although better than the match between SRTM and GEBCO, systematic errors were observed in the product, related to the ability of the NDSI to define water, and availability of tidal statistics; suggesting there is room for improvement.

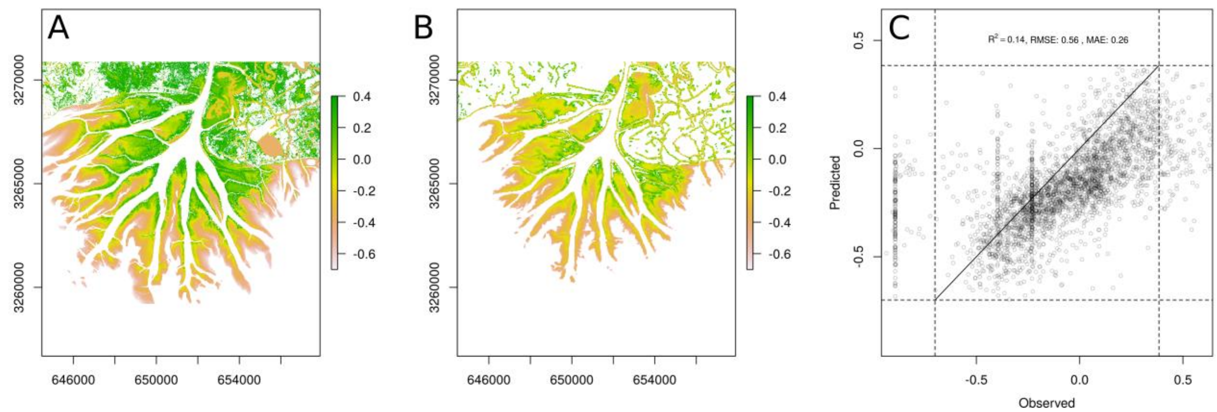

Figure 4. Example of validation of the FAST intertidal elevation product (m, LMSL) at Atchafalaya Delta, LA, USA. A) Observed elevation derived from the USGS Coastal National Elevation Database (CoNED) Project - Topobathymetric Digital Elevation Model (TBDEM, https://lta.cr.usgs.gov/coned_tbdem), B) predicted elevation, C) scatterplot of observed and predicted elevation.

4.2. Global Vegetation Presence

The low resolution of global land cover maps led us to develop a simple estimation the presence/absence of vegetation in coastal zones using USGS Landsat and Copernicus Sentinel 2 images between 2013 and 2017.

The binary presence of vegetation was determined by fitting a harmonic function to a time-series of Normalised Difference Vegetation Index (NDVI) images, and segmenting images representing the fitted harmonics using a threshold for both the mean, and amplitude of the NDVI harmonics. As for the intertidal elevation, processing was carried out on ~ 20000 AOIs covering the global coast (defined using Open Street Map tiles) in Google Earth Engine, and took ~ 20 days.

5. CONCLUSIONS

The MI-SAFE platform is an example of a marine IGIS assembled with OS components that provides a fully OGC compliant solution. The platform makes it easy to include new data, and can facilitate the demonstration of advanced commercially available data layers. One major advantage of the system is that processing of large volumes of EO data is carried out using the cloud native Google Earth Engine, which substantially reduces storage issues, and allows rapid development of new products.

The purpose of the platform is to support Nature-based Solutions for coastal defence, helping users understand how vegetated foreshores reduce coastal flood risk, and providing key data resources to enable expert users with their own modelling efforts. This knowledge will help to reduce the cost of flood protection, as well as deliver inputs towards wide-spread, successful restoration and conservation of coastal ecosystems.

6. REFERENCES

[1] Morris, E. P., Jesus Gomez-Enri, and D. Van der Wal. 2015. ‘Copernicus Downstream Service Supports Nature-Based Flood Defense: Use of Sentinel Earth Observation Satellites for Coastal Needs’. *Sea Technology* 56 (3): 23–26.

[2] Van Koningsveld, M., G. J. De Boer, F. Baart, T. Damsma, C. Den Heijer, P. Van Geer, and B. De Sonneville. 2010. ‘OpenEarth-Inter-Company Management of: Data, Models, Tools & Knowledge’. In *Proceedings WODCON XIX Conference. Beijing, China*.

[3] Van Rooijen, A. A., R. T. McCall, J. S. M. Van Thiel de Vries, A. R. Van Dongeren, AJHM Reniers, and J. A. Roelvink. 2016. ‘Modeling the Effect of Wave- vegetation Interaction on Wave Setup’. *Journal of Geophysical Research: Oceans* 121 (6): 4341–59.

[4] Mason, D. C., I. J. Davenport, and R. A. Flather. 1997. ‘Interpolation of an Intertidal Digital Elevation Model from Heighted Shorelines: A Case Study in the Western Wash’. *Estuarine, Coastal and Shelf Science* 45 (5): 599–612.

[5] Murray, Nicholas J, Robert S Clemens, Stuart R Phinn, Hugh P Possingham, and Richard A Fuller. 2014. ‘Tracking the Rapid Loss of Tidal Wetlands in the Yellow Sea’. *Frontiers in Ecology and the Environment*, May. doi:10.1890/130260.

[6] Muis, Sanne, Martin Verlaan, Hessel C. Winsemius, Jeroen CJH Aerts, and Philip J. Ward. 2016. ‘A Global Reanalysis of Storm Surges and Extreme Sea Levels’. *Nature Communications* 7.