Earth Observation for Coastal Management

ARGANS

Introduction

Coastal Erosion presents a pressing and increasing management problem with irreconcilable social and economic implications. Erosion is not continuous and will vary according to season and anthropogenic intervention. Many factors influence erosion; however, it is self-evident that climate changes will bring an increased frequency and intensity of storms to our coasts which will exacerbate changes. Mapping and monitoring coastline change using satellite observations enables a new, nationwide perspective to observe the effect of these changes over multiple timescales and support the ability to forecast future change. Satellite information provides support for the implementation of strategies that can be taken to mitigate such changes.

Satellite data is vast and complex. Therefore, the product users, engineers and decision makers will need an understanding of how current and historical coastline products are derived so that analysis can be performed. These products can then be used within Geographical Information Systems (GIS) to provide accurate data for enhancing decisions and reducing costs. This document has been designed to help the reader better understand the utility of Earth Observation (EO) products through an explanation of:

- How satellite data can enhance Coastal Management Planning.
- How coastal change is measured from space.
- How Earth Observation products can be used in Integrated Coastal Management.
- How to access coastal erosion products derived from satellite data.

Coastal Erosion at Withernsea in East Yorkshire (BBC News).

How can satellite data enhance Coastal Management Planning?

Satellites orbit the Earth in a predictable manner and collect images of the same location at a regular interval. A continuous orbit enables the missions to acquire data at a regular frequency and allows large repositories of data to be collected. This data can identify changing conditions on the ground through time. Spaceborne sensors also offer high spatial resolution[1] and collect information over specific spectral bands which encompass a range of the electromagnetic spectrum. This supports varied analysis and increases the insights derived.

Coastal managers have a need for current and historical spatial data at a frequent temporal range and in sufficient enough detail to identify changes. This can be provided through satellite information. A repetitive image capture allows changes to be tracked regularly to establish patterns over large areas that are impractical to survey in the field. Satellite images have also been captured over a decadal timescale and so a long-term historical analysis can be conducted. This makes satellite imagery an indispensable, efficient and cost-effective tool to aid decision making.

[1] Sentinel-2 and LANDSAT are two commonly used open-source sensors. They offer a spatial resolution of 10m and 30m, respectively. Data is provided across the EM Spectrum ranging from 400 – 2400nm for Sentinel-2 and 433 – 2300nm for LANDSAT. See here for more information: https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/resolutions/spatial

When using earth observation, there is often a compromise to be made between cost, the spatial resolution, temporal resolution, signal to noise ratio and spatial accuracy of sensors. Therefore, studies require an understanding as to which of these parameters is the most appropriate for their subject of interest. A tendency can exist to prefer sensors with the highest spatial resolution; however, these may not always be the most appropriate for comparison studies and will come at a much higher price. A balance should be considered based on the criteria required for specific decision-making processes. This includes: the positional accuracy of data required to identify real change (erosion rates are often observed in metres rather than tens of meters so the positional accuracy for derived products must meet this need), the repeatability of image acquisition (in order to bracket real events such as storm surges or the effects of sea defence construction) and quality of spectral reflectance (to distinguish different objects on the ground as opposed to differences in the pixel representation).

The process of selecting appropriate satellite parameters, processing and analysis methods is pivotal for understanding the situation on the ground and establishing how these can impact management problems. In addition, satellite derived data and products can often be checked against ground truth measurements and observations to provide a level of validation of the approach adopted. Validated datasets are reliable and can cut costs, streamline processes and provide new avenues for analysis.

How is coastal change measured from space?

Coastal areas can be dynamic environments which are constantly subject to change. Monitoring change to the coastline is vital for communities that live along coasts especially with sea level rise and increased storm intensity with climate change. Traditionally, coastal erosion was measured in extensive in situ survey campaigns. These can be prohibitively expensive in cost and time, and they are impractical to deliver over regional or national scales. This can be demonstrated through the consideration of the length of the coastline of mainland Great Britain which is defined by The Ordnance Survey as approximately 17,000km. This equates to 34 individual Sentinel-2 satellite images and represents over 4TB of data which will need to be processed and analysed.

Coastal retreat can naturally vary dramatically through the seasons as well as on an annual basis. Therefore, analysing a range of spatial and temporal scales is the only option for a comprehensive understanding of these processes. A regular cadence of assessments can establish whether a coastline experiences long term erosion or more complex patterns of seasonal gain and loss. Identifying and differentiating between short- and long-term change will enable a thoroughly representative view of the changes to be understood and support effective resource allocation. This is especially true if the desired solution involves structural engineering constructions or land purchase to enable a nature based managed realignment. If decisions are conducted on sparse data, then there is a danger of aliasing. This occurs when the coastal change analysis is not conducted at an appropriate frequency to provide a realistic picture of the conditions occurring. A timeseries that demonstrates historical patterns is the optimal approach to fully understand the sediment system and to shape operational plans, however, this is often prohibitively expensive through repeated in-situ surveys.

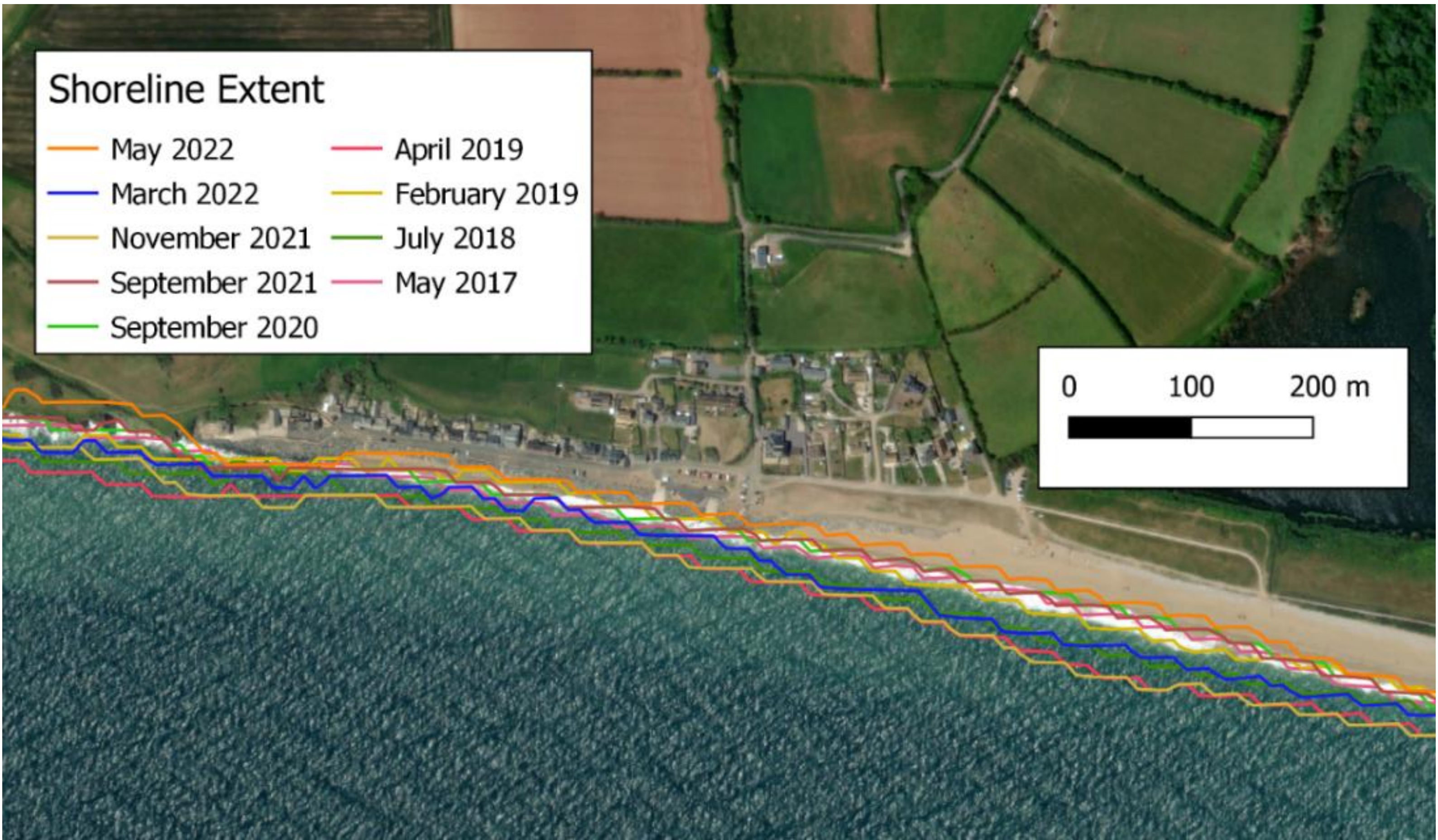
A range of processes are monitored to indicate erosion; these include shoreline extent and change, sediment mobility and bathymetry. In practice, this first requires the specific identification of the land-sea boundary. The frequency at which these indicators are measured can be adapted to specific end user requirements and the dataset presents fundamental information to enable evidence-based planning for the mitigation of hazards by decision makers.

SATELLITE DERIVED PRODUCTS

Waterline Product

An indication of the horizontal boundary between land and sea is demonstrated through the derivation of waterlines. They provide an instantaneous land/sea delineation at the time at which the satellite image was taken. The exact position of the waterline is based upon the height of the tide at the time of measurement and whether any meteorological conditions (such as low pressure and strong waves) are influencing the waterline position. In addition, the shape of the beach can change and contribute to the position and shape of the waterline.

To accurately identify the boundary between the land and sea, an analysis of spectral characteristics is performed along the coast by looking at small segments of coast to derive a specific wet/dry threshold. Through this locally adapted threshold a more accurate waterline is extracted by taking into account neighbouring pixel information. An internal quality control process evaluates the waterline according to requirements including the length of the line, its rugosity and other geometric features which would be absent in reality. This quality control score provides confidence in the results. All available waterlines (which consist of those that are not obscured by cloud) are extracted so that an annual and/or seasonal assessment can be made. This assessment can support regular monitoring tools, improve short-term response to natural disasters and evaluate programmed expenditure.



Waterlines are a vital step to derive shorelines which are important in establishing the variation of the coastal boundary and whether it experiences change over time. Waterlines will also naturally vary based on tidal conditions and so will not provide a proxy for monitoring coastal change over time independently. Therefore, these must be transformed to datum-based lines known as shorelines by accounting for beach slope and water height mostly by using auxiliary data.

Shoreline Product

A waterline is converted to a shoreline through a horizontal displacement due to the correction of tide related to a tidal datum, fluctuations of wave conditions and beach slope. Therefore, a shoreline represents the intersection between land and sea where the sea water level corresponds to a defined elevation above a fixed datum benchmark. Examples of these theoretical datums could be Mean Tide Level or Mean High Water Springs or Lowest Astronomical Tide. These datums need to have been established, however.

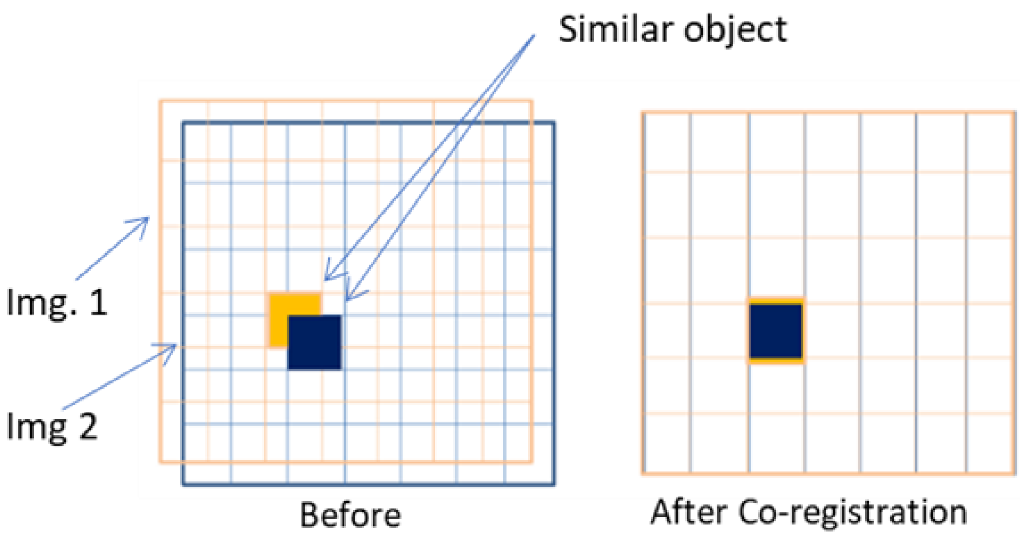
Continuous shorelines can be mapped over decades using satellite data and analysed using GIS software. Coastal change associated with seasonal variation, storm events, human interventions (such as sea defences and coastal construction) and long-term trends can then be determined. Regular assessments can establish complex patterns of seasonal gain and loss from which an estimate of change rates can be calculated. This knowledge will guide effective coastal management.

Mean annual shoreline change derived from the differences in individual shoreline extents.

Ensuring Product Accuracy

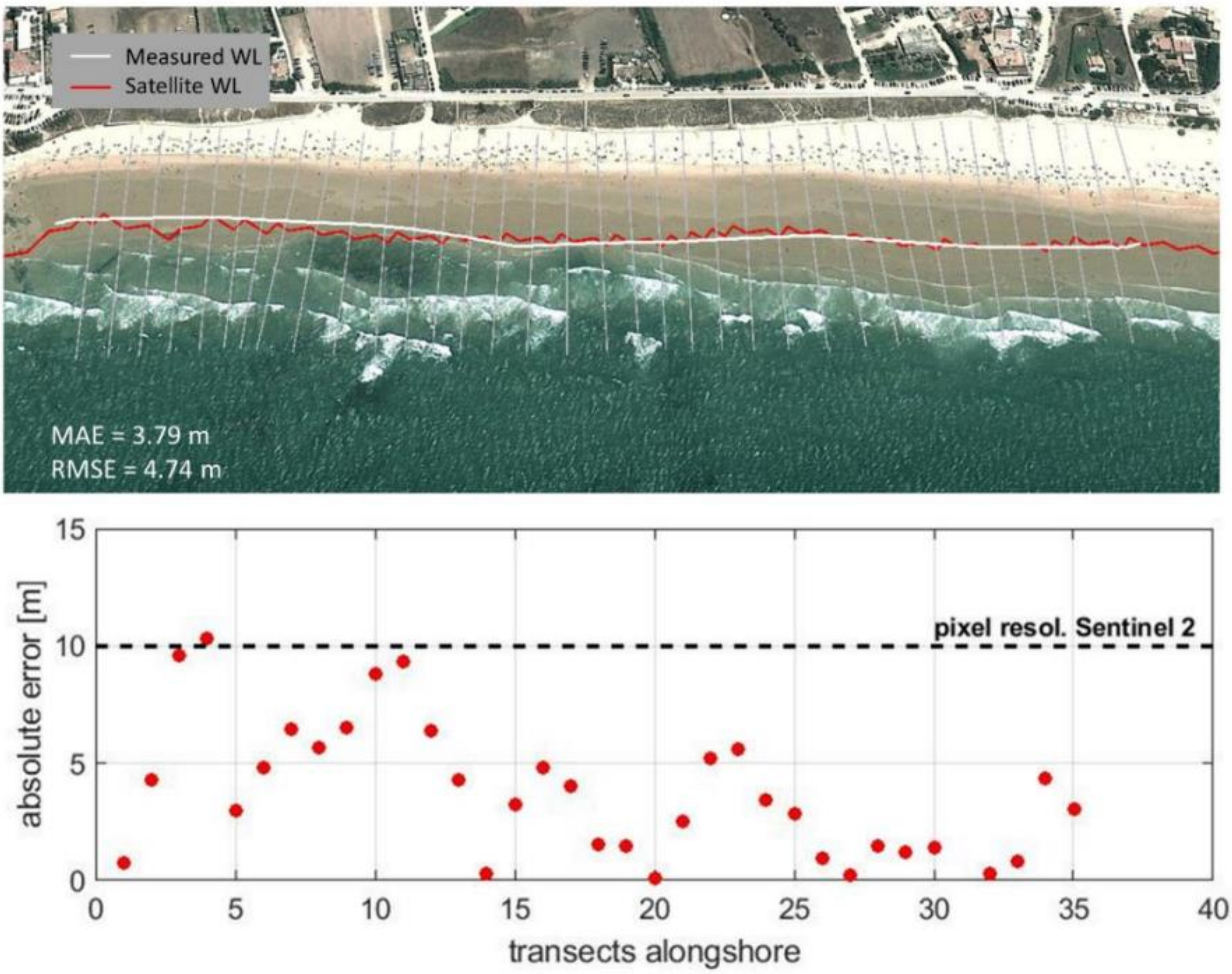
A high positional accuracy of products is ensured through co-registering pixels to commercial imagery (satellite or aerial photography) of a higher spatial accuracy. When images are taken at different times or by different sensors, they can have slight differences in their geographic location, orientation, and resolution, which can affect the spatial accuracy of the final product for comparison and interpretation. Co-registration is the process of aligning two or more images taken by different sensors or at different times. This ensures the perfect overlap of different objects in order to enable a comparison of these images to be conducted over a period of time.

This is an important step in many remote sensing applications, such as change detection, where it is necessary to compare images of the same location taken at different times. By aligning multiple images through co-registration before our processing chain commences ensures that the accuracy of all the images is improved, and the resulting data can be used to reveal real changes in the landscape over time, such as coastal erosion.



Independent Product Validation

During the development of this service, a validation of the resultant products has been performed by national geological authorities within the UK, Spain, Italy, the Republic of Ireland and the province of Quebec. This has ensured that the EO data product quality is reliable, accurate and precise. Product accuracy is expressed as the Root Mean Square Error (RMSE) and represents a measure of the distance from the actual position within which points are expected to lie. The accuracy analysis indicated that Mean Absolute Error (MAE) and RMSE values were always bellow the pixel resolution of the satellite images from which the products were obtained (Landsat and Sentinel images present 30m and 10m resolution, respectively).

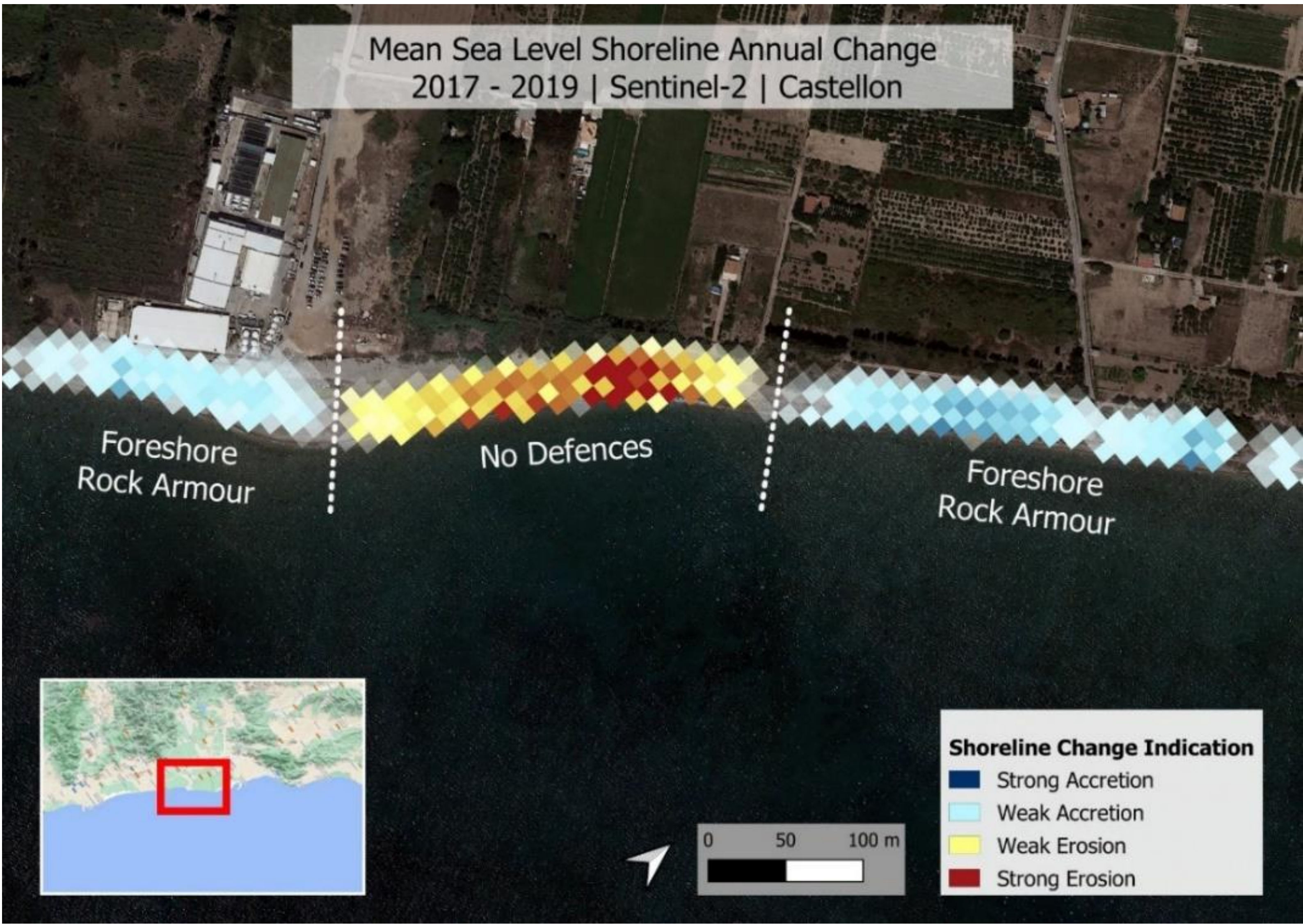


Positional accuracy of waterlines in Tordera, Barcelona.

How can Earth Observation products be used in Integrated Coastal Management?

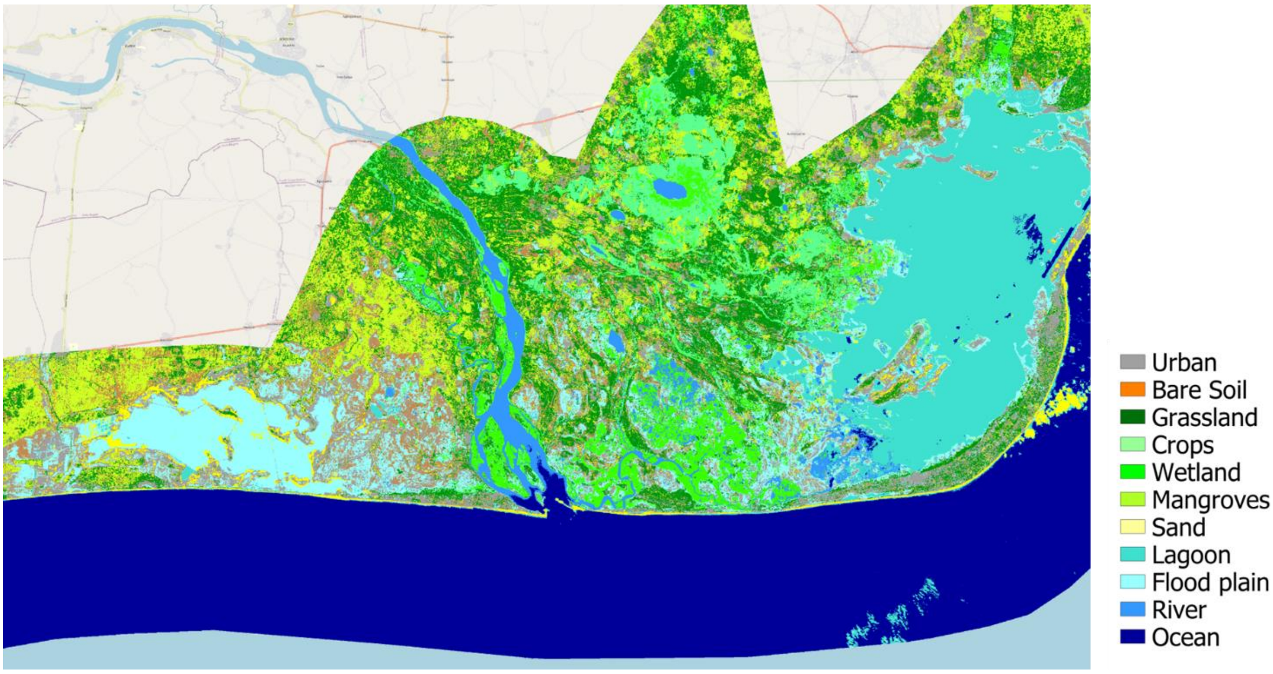
These coastal change products will help coastal managers conduct new analysis of the coastal zone to enhance management decisions. Products from this service will provide new insights and enable the delivery of services at new spatial and temporal scales to increase the efficiency of monitoring strategies.

Satellite derived shoreline data can be used to monitor changes in the coastline over time to evaluate processes such as erosion and accretion. Patterns of seasonal erosion can be compared to long term retreat to allow the intelligent placement of defences and ensure the efficient prioritisation of investments in long term management plans.



Quantifying the baseline processes over a long time-series identifies the physical properties of the coastal environment to measure and assess the environmental effects of Shoreline Management Plans (SMPs). SMP guidance can define sustainable long term management policies as those which take account of the relationships with other defences, developments and processes, and which avoid, as far as possible, committing future generations to inflexible and expensive options for defence (Defra, 2006). Remote sensing data quantifies these interrelated processes at scale and removes the need for manual and regular surveys in situ. One such example is to map patterns of sediment transport along the coast, which can inform decisions about beach replenishment projects and other erosion control measures.

Satellite data can be used to identify and map different coastal ecosystems. Observed changes to the shoreline can indicate the gain or loss of buffer areas providing natural protection to coastal erosion. The extent and change of these priority ecosystems can be identified, including mangroves, salt marshes, and coral reefs. This information can help coastal managers compile strategic environmental assessments which can prioritize conservation efforts and identify areas that are vulnerable to loss or degradation to inform land use planning, manage realignment and offer nature-based solutions. The areas identified that are most in need of restoration, such as degraded wetlands or eroding shorelines, will help to prioritize restoration efforts based on their potential impact on erosion reduction.



Coastal Ecosystem classification around the Volta estuary, Ghana

Overall, satellite data can provide valuable information to support coastal management decisions related to erosion, which in turn can help to protect coastal communities and ecosystems from the impacts of erosion and sea level rise.

The Coastal Change from Space data service

The Coastal Change from Space global data service has been developed by ARGANS to deliver and simplify the detection of annual and seasonal coastal changes. This data monitors the condition of coastlines and can be produced to cover anywhere in the world at a 10m resolution with a spatial accuracy of 1 to 2m starting at 2015. Historical data can extend back until 1984 at a 30m resolution. While new image acquisitions from 2017, can be provided at 5 day repeat period using free to access missions. This allows a high degree of analysis to determine whether changes observed represent manmade intervention, natural seasonal fluctuations or are indicative of longer-term structural decline in the past, present and into the future. Semi-automated techniques of coastline detection have been applied to quickly process a vast catalogue of existing satellite imagery. These can be integrated rapidly into coastal change models and are provided in a format which can be integrated into any Geographic Information System for specific management applications.

The service can provide significant insights into determining where investments by authorities should be focused and how corrective actions can be best targeted in the framework of climate adaptation strategy. The service is composed of the following components:

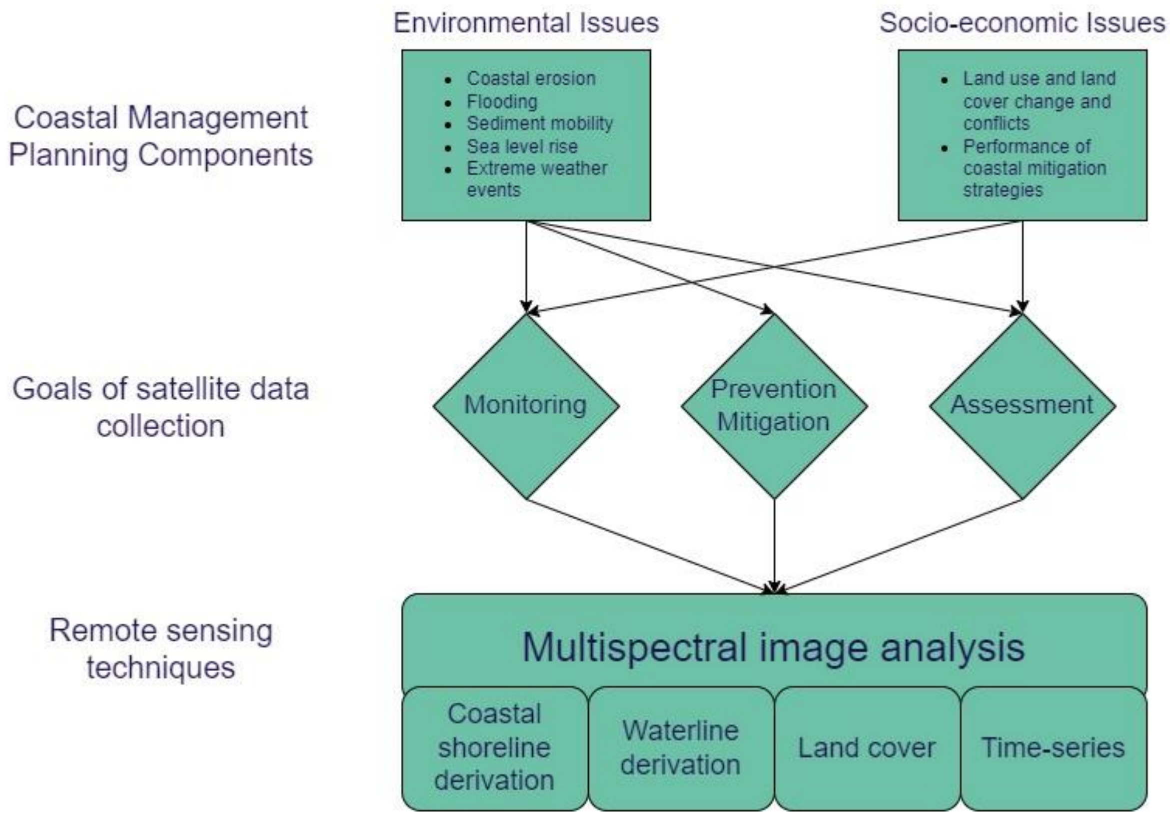
1. Access to open-source data from Copernicus Sentinel-2 and LANDSAT images provided by ESA and the United States Geological Survey.
2. Bespoke EO processors to produce a characterisation of the nearshore area:
    a. A spatially accurate (+/- 2m) delineation of the waterline with a Quality Control score.
    b. A derived datum referenced shoreline position. This correction requires additional knowledge or auxiliary data related to beach slope and tides.
    c. Classification of the land cover of the backshore area to improve risk assessment.
3. These products are derived from 10m resolution datasets with a five-day lag between repeat acquisitions (depending on the weather conditions).
4. Image distortions are corrected and spatial accuracy improved through image co-registration.
5. These derived products have been validated by professionals in partner nations, including British Geological Survey, The Hydraulics Institute at Cantabria (Spain), Geological Survey Ireland, The Italian National Institute of Environmental Protection and Research and ARCTUS working with the University of Quebec at Rimouski.

Experience gained over the course of the various coastal erosion projects conducted by ARGANS Ltd and its partners have covered more than 5000km of coastlines, observed across 21 differing geomorphological sites to demonstrate that the innovative techniques developed are truly scalable worldwide. Nations supported include the UK (complete mainland GB coverage), Italy, Spain, Ireland, Quebec province and Ghana.

Data access

Coastal change products for any region on the globe can be ordered through the ARGANS data service. Please see our website for more information: https://coastalerosion.argans.co.uk/ or contact us at coastalerosion@argans.co.uk.

The role of remote sensing in Coastal Management Planning



Acknowledgments:

The Coastal Erosion from Space project, 4000126603/19/I-LG, was commissioned under the Science for Society slice of the 5th Earth Observation Envelope Programme (EOEP-5) of the European Space Agency.

The Headlines **The consortium developed a method to optimise the number of customer ready co-registered waterlines and datum referenced shorelines seasonally covering 25 years that have been validated by the leading technical geomorphological experts within the five partners' nations. Over 4000Km of coastline was mapped. These products deliver inter-pixel accuracy, use a locally adaptive threshold method to accurately determine the position of the land/sea boundary precisely and can be scaled to cover complete nations worldwide. Indeed, each partner nation intends to continue this work to provide national coverage. We have developed a land classification map that describes the coastal strip, including coastal features and their inter-annual changes which enable beach width to be determined. Boundaries have been pushed using satellite derived bathymetry techniques based on a long history of this technology to observe features of interest even in the sediment loaden waters.**

This project has been led by ARGANS Ltd who formed a partnership consisting of an EO based information service provider group of Earth Observations and Data experts comprising ARGANS Ltd (UK/Fr), isardSAT (Spain) and adwaïsEO (Luxembourg) who delivered to an authoritative public User Group of national representatives from the British Geological Survey, the British government experts, IHCantabria in Spain on behalf of the Spanish government's Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO), Geological Survey Ireland, the Irish Department of Environment, Climate and Communications and ARCTUS representing the Canadian academic world and the local communities of Québec. For the CCN an additional national expert from Italy was added to the consortium, namely the Italian National Institute of Environmental Protection and Research.