Collaborative and flexible processing infrastructure for Coastal Monitoring

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***Abstract*—Coastline Watch aims to assess the best practices to continuously monitor changes caused by natural processes (such as waves, tides and currents) and strengthen by human intervention or global climate changes. The current solution processes coastal information from Satellite open data for monitoring and makes *insitu* measurements using Unmanned Aerial Vehicles (UAV) for impact analysis. It uses a collaborative infrastructure to make processing requests, analyze and share the resulting outcomes with a project team. The first experimental processing service implements a shoreline monitoring chain to detect changes, to establish trends and indicators and to identify potential risks and critical areas. The service uses Landsat program data and it is prepared to support other open or commercial satellites, such as the Sentinel program. After identifying critical areas, the solution uses a methodology to determine impact of changes by making aerial data acquisitions and then estimating surface volumes changes. A cloud infrastructure, based on Amazon AWS technology, provides a distributed environment solution composed by a web portal, processing resources and an OGC database. The portal allows the users to generate new coastal products based on automated scripts, to share the results with the team and to view/download the final products. The service is being demonstrated on the coastal areas of Figueira da Foz and Óbidos lagoon over specific timeframes, being iteratively fine-tuned with users/researchers feedback. The current infrastructure is still under consolidation, with the final goal to provide automated processing tools and a methodology that could be collaboratively and continuously updated by researchers and professionals to generate data from new areas and update existing ones.**

Keywords—Coastal Zone Management, Cloud Infrastructure; Collaborative tool; Satellite Open Data; Unmanned Aerial Vehicles; Automated processing tools

I. Introduction

A. General Objectives

Coastline Watch aims to continuously monitor coastal changes caused by natural processes (such as waves, tides and currents) and strengthen by human intervention or global climate changes (e.g. sea levels rising). Those changes, typically manifested by erosion and accretion processes, can result in coastal disturbances with potential economic and environmental impacts as well as increase the risk for the citizen's safety and security.

The actual implementation described in this paper aims to demonstrate the best monitor practices among coastal areas using Satellite Open Data and Unmanned Aerial Vehicles (UAV) for making *in situ* measurements. The implementation is also prepared to evolve and provide coastal indicators and specialized services to final users. The solution uses a cloud infrastructure aiming to host three services:

- Monitoring service to process and extract useful information from satellite Open Data
- Intelligence Service to obtain coastal indicators, trends and identify potential risks
- Impact Service to make in-situ measurements (e.g. unmanned aerial systems), namely in the context of occurrence of harmful events.

B. Trends and Needs

The current Earth Observation (EO) context is being driven by an increasing launch of satellites, with better temporal, spatial, radiometric and spectral resolution and also the emergence of the satellite Open Data programs (such as Landsat and Sentinel programs) with long term continuity strategy. On the other hand technology usage trend is converging to cloud and mobile oriented solutions, using Software as a Service (SaaS) products.

In this scenario, professionals and researchers needs **processing tools** to acquire and process a large amount of archived open satellite image data. Automation of processing services is a need (refer to [1]) and it is desirable to explore **collaboration** tools and methodologies. This paper focuses on demonstrating the potential of using the automation and collaborative techniques for processing open data.

C. Processing infrastructure objectives

The first step towards the implementation of Coastline Watch general objectives were the development of minimal processing infrastructure described in this document with the following objectives:

- Provide a monitoring infrastructure for researchers and professionals, using a cloud flexible infrastructure based on a plug-in architecture to allow adding new services (Monitoring Service)
- Consolidate the UAV methodology (Impact Service)
- Make demonstrations within specific coastal areas

- Assure the sustainability of the infrastructure for operations and evolving to new developments

D. Background

Coastline Watch is being developed since 2014. In order to present a cost-effective monitoring tool for the typical Coastal problems the authors are being focused in the use of open data, automatic processing and collaborative tools. In this way:

- The authors started by making several scientific publications in key areas of the proposed solution, including using satellite open data [1], monitoring of coastal changes [2], monitoring shallow waters [3] and data acquisition with UAV [4].
- In October of 2014, the project was awarded with the 3rd place on the DLR Energy & Environmental Challenge of the Copernicus Masters 2014 which is a contest looking for new applications in Earth Observation addressing climate, environment mapping or sustainable energy management.
- The authors, with the support of the research community, are now developing a cloud infrastructure composed by with a web user front-end in Ruby on Rails to request the processing of EO products (Amazon EC2, S3), an OGC database to store results (Amazon RDS) and a visualization console for indicators (Ruby on Rails).

II. Open Data Processing Infrasturure

The processing infrastructure from Monitoring Service will observe continuously changes in relevant coastal areas, and uses Satellite open data. It follows a plug-in architecture to support multiple applications. The initial set of applications aims to monitor the shoreline relative position and also land cover changes at coastal zones, such as vegetation changes in primary sand dune fields. Both applications are typically performed in yearly basis and, in some cases, with two or more products per season (dry and wet season) depending on the user specific requirements. Also, the monitor service could be also used for making on demand requests after a particular occurrence/event in order to allow making a post event analysis (this feature will take advantage of the Sentinel-2 revisit time of 5 days when the mission becomes operational).

A. Open Data

The primary source of data comes from Landsat and Sentinel programs, in particular from Landsat-8 and Sentinel-2. Landsat is now the longest continuous Earth imaging program, starting with Landsat-1 in 1972 up to Landsat-8 in 2013. Landsat-8 has a revisit time of ~16 days, a spatial resolution of 15 meters and 11 spectral bands. Sentinel satellites are included in Europe's strategy for the development of Copernicus program and will provide enhanced continuity from Envisat (2002-2012). These open data satellites will be available with better temporal and spatial resolution, achieving a revisit time of 5 days with 2 satellites and a spatial resolution of 10 meters. The combined revisit time of all available open data satellites has higher potential and has encouraged the development of Coastline Watch.

The Open Data sources used by the solution is summarized in table below and includes other auxiliary data, such as EEA Corine CLC, High-resolution layers datasets or in some cases national ortho-photomaps.

TABLE I. Open Data Sources

Dataset name	Dataset origin	Dates	Dataset license
Landsat Program (8, 7 and 5)	USGS/ NASA	1982-…	Used or redistributed as desired
Sentinels program (Sentinel-2 and Envisat)	EC/ESA	2002-2012 2015-…	Free, full and open data policy adopted for Copernicus
EEA Corine CLC	EEA	1990, 2000, 2006, 2012	Free access for all users
EEA High-resolution layers	EAA	2009	Open access

B. Flexible Infrastructure

The Coastline Watch implementation is a Software as Service (SaaS) solution developed and deployed in a cloud infrastructure. It is composed by portal with a web user interface, a processing instance for EO products processing, a storage instance and an OGC database to host the final products, as depicted in Fig. 1.

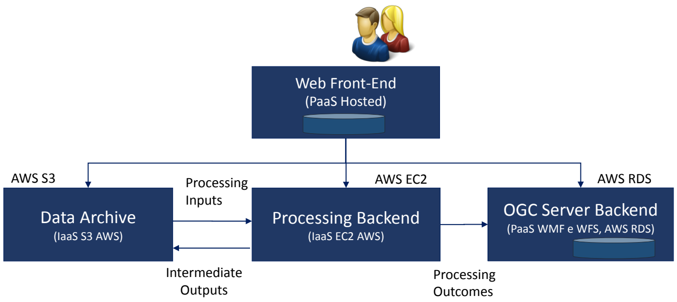

Fig. 1. Main system modules

The logical modules are implemented using different Platform as a Service (PaaS) and Infrastructure as Service (IaaS) providers, as described below:

- Web Front-end – provides the web front-end access of the system and manages the business middle tier logic, such as Satellite data processing and Intelligence (PaaS).
- Data Archive – acts as a storage point for image and temporary data (IaaS S3 AWS).
- Processing Backend (IaaS EC2 AWS) – cloud computing for processing the primary source images.
- OGC Server Backend – this module hosts the outcomes of the processing on a PostGIS database and WMS and WFS services (PaaS Amazon RDS AWS, PaaS WMF e WFS).

The key issue is to provide a friendly web user interface with a flexible infrastructure that will request processing and storage resources on demand without need to have a permanent machine with the project data. The user will have available a service storage and an automated processing chain upon request to produce the desirable outcomes. The system will also allow abstracting the professionals and researchers from the computational resources and configurations details.

The first processing chain was a service for shoreline extraction and monitoring, but the infrastructure is also modular enough to allow the addition of new services such as Land Cover changes and water monitoring. An Intelligence service to produce indicators from the services processed, such as the shoreline historic evolution, trends and post-event analysis, sea tides analysis or coastal changes indicators, are being considered.

The implementation is a distributed system using AWS interface services and on demand computational resources (see Fig. 2). For demonstration purposes it was used with the following Amazon services: Amazon Elastic Compute Cloud (Amazon EC2), Amazon Elastic Block Store (Amazon EBS), Amazon Simple Storage Service (Amazon S3) and Amazon Relational Database Service (Amazon RDS).

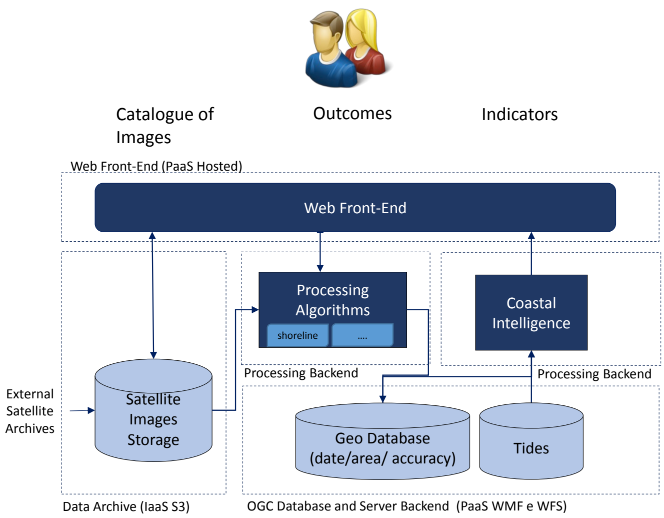

Fig. 2. Architecture and Physical Deployment

Nonetheless, the implementation can be done with other public and private cloud infrastructures as far as it supports AWS interfaces [5].

C. *Automated Processing Services*

Many existing remote sensing algorithms are published and well-known and some are scientifically quite mature. In some cases, they are not fully automated or not optimized or not robust enough to be operational. The Coastline project looks for the development of automated processing implementations to operationalize the existing algorithms. Our first automation was the shoreline processing that was possible with OTB [6], QGIS [7], SAGA [8] and GRASS [9]. Although a few improvements are being performed at the time of writing, such as the pixelate effects from the extracted products, Fig. 3 presents the main processing steps used in the shoreline automation.

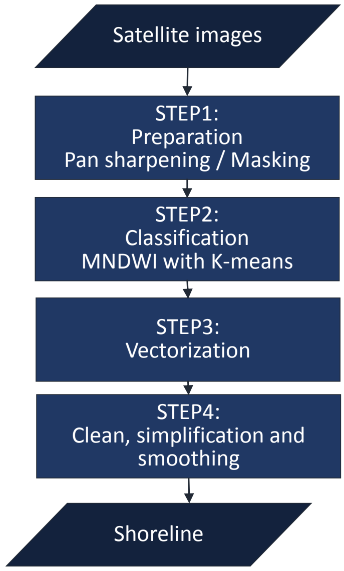

Fig. 3. Shoreline Automated processing

The preparation step enhances the images resolution through a pan sharpening processing (for example, for Landsat images we can improve the spatial resolution up to 15 meters) and masks the clouds and area of interest. The following step produces an image classification from water index while the vectorization converts the water delimitation into a vector. The final step is about removing the inland water bodies and smoothing vector pixelate effects.

This automation process can produce a rapid shoreline mapping but in most cases the results still require users' validation. Moreover, it is worth to note that it is also feasible to automate land cover classification using pre-defined training data to quickly obtain coastal land cover maps.

D. *Collaborative approach*

The solution follows collaborative approach between the registered users, typically researchers and professionals. The front-end portal (briefly described in the Fig. 4) defines the concept of project and supports two main user roles. Expert users can generate new coastal products based on automated scripts and general user can view and review the product outcomes.

A user can create a new project, invite other members to join the project and then share the results with the team or allow them to produce new shorelines on this project. Any project member can then review the outcomes produced within the project and export and download the resulting outcomes. On later development stage, cross-project data may be used to generate general indicators from on shorelines produced within each project.

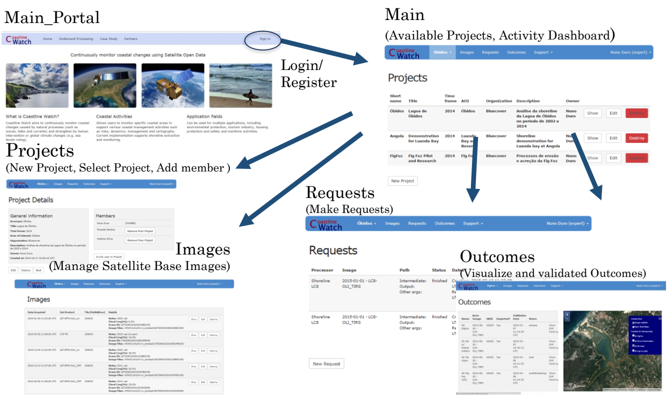

Fig. 4. Front-end portal functional overview

III. Unmanned Aerial Vehicles

After the users have identified the critical areas, in-situ fine 3D measurements are preformed using a UAV photogrammetric methodology. Fig. 5 shows the general flowchart for using UAVs to track the geometric changes on primary sand dunes. First, it is supposed that a reference Digital Surface Model (DSM) is available[1] for the area of interest. Second, using the UAVs images and the Ground Control Points (GCPs) taken by RTK-GNSS geodetic receivers a DSM is computed using a Structure from Motion (SfM) approach ([10], [11]). These DSM time series will enable to compute profiles (1D), surface (2.5D) and volume (3D) changes from the base line surface.

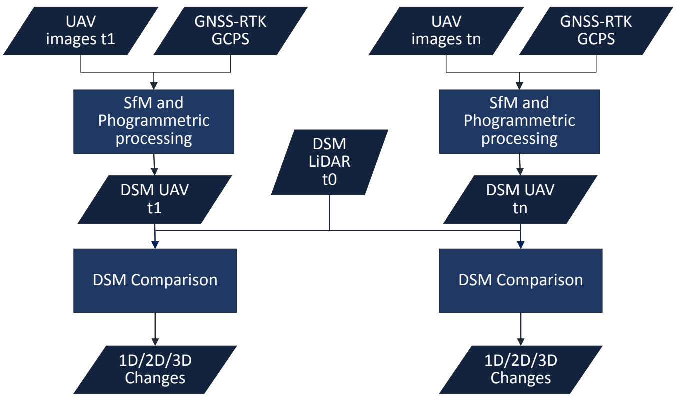

Fig. 5. Tracking geometric changes on primary sand dunes with UAVs

It is worth to note that this Impact Service aims to be performed on a specific critical area upon user confirmation and interest. In this case, a reference DSM has to be available (Fig. 8) and the further UAVs acquisitions and processing can be performed in a collaborative data acquisition scheme or via commercial requests.

1 In the case of the Portuguese coast this reference baseline is a Light Detection and Ranging (LiDAR) DSM with a horizontal resolution of 2m.

IV. Results

The service demonstration is being performed on the coastal areas of Figueira da Foz and Óbidos lagoon over a specific timeframe. In Figueira da Foz, an inter-annual analysis from 2000 to 2014 was made to detect historical displacements and trends. Indicators of erosion and accretion processes were detected, such as the two areas represented in figure.

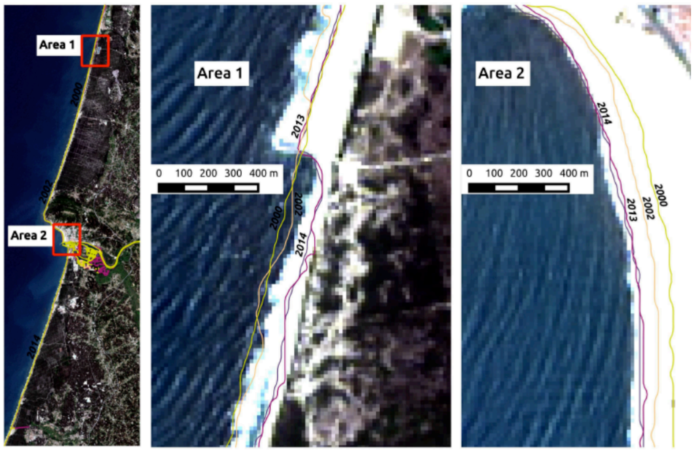

Fig. 6. Shoreline annual analysis at Figueira da Foz

Also, the shoreline analysis may be used to study the intra-annual dynamics and influence of tides on coastal lagoons ecosystems, such as the study that is being developed at Obidos lagoon in 2014 (dry season) and 2015 (wet season).

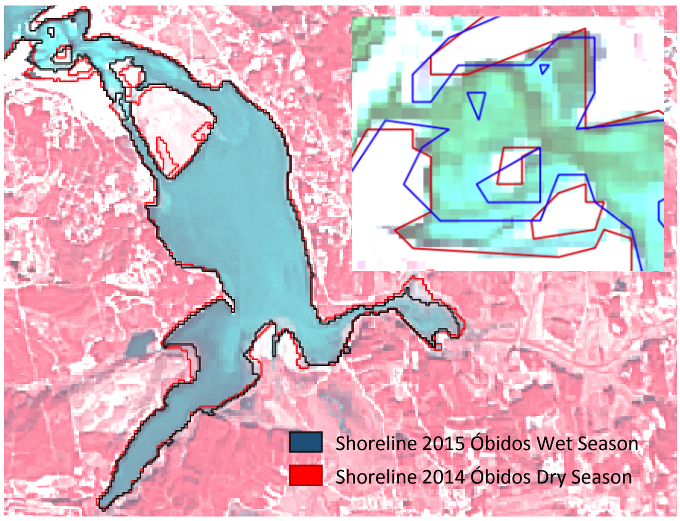

Fig. 7. Boundaries of Óbidos lagoon during Dry and Wet season 2014/2015

These demonstration products are being evolved iteratively with user feedback and assessment. The current implementation of the shoreline extraction allows to:

- Demonstrate the shoreline processing automation
- Create a structured database of various chronological shorelines baselines
- Demonstrate the collaboration between users seems relevant (although it is now starting to be developed).

Nevertheless, the resulting data needs to be interpreted and assess by researchers, specialists and professionals. The preliminary results indicate that the produced data can be used to:

- Identify Areas displacements
- Provide a historical overview of the shoreline evolution
- Analyze the dynamics of coastal (inland) waters and possibly using animated film from the registered situations

The Open Data, per si, may not sufficient for all cases and higher spatial resolution may be needed, acquired either through satellite or aerial survey. Existing processing algorithms can be adapted for this purpose and thus reusing existing work.

Fig. 8 shows an example of the Impact Service for UAV image acquisition for a specific coastal area (Fig. Foz). For this case study the main objective was to detect the volume changes on primary dunes. On March 9, 2015 a multi-rotor quadcopter UAV equipped with a 12MP consumer grade digital camera (a GoPro Hero4 Silver) was flown at an altitude of 100 meters (ASL). The 140 acquired pictures, covering an area of 7ha, were processed with an open source photogrammetric software [11]. From the 3D point cloud (illustrate in Fig. 8) a DSM with a spatial resolution of 10cm was generated with a horizontal and vertical accuracy of 10 cm and 20 cm, respectively. This DSM was accurate enough to detect the changed volume in the primary sand dunes from the base line reference DSM.

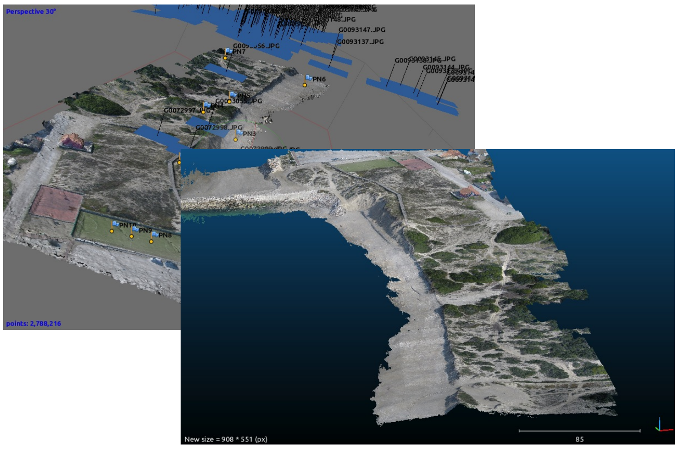

Fig. 8. UAV image acquisition and processing of primary dunes in Fig. Foz

Besides the computation of the changed volume on primary sand dunes, the UAV acquisitions will definitely provide further details on coastal monitoring.

V. Conclusion

The infrastructure described is not the final goal but the first step to develop an operational system for coastal zone monitoring. The infrastructure is now being demonstrated and the effective evaluation of the researchers and professionals will take place in next months.

The future work will include research on the Intelligence service (Indicators) and on the development of new processing services (such as coastal land cover changes, shallow-waters bathymetry). The extension of new services is quite important to complement the existing information and enforce the utility as a tool for coastal monitoring. It will aim to:

- Provide precious information about the coastal areas dynamics for public authorities and tourism.
- Conveniently identify territorial vulnerabilities.
- Support the prevention of people and goods

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