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Coastal Waters Research Synergy Framework

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Research Applications

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Acronyms and Abbreviations	
AOI	Area of interest
CMS	Corporate Management System
Co-ReSyF	Coastal Waters Research Synergy Framework
DEM	Digital Elevation Model
EO	Earth Observation
FFT	Fast Fourier Transform
GUI	Graphical User Interface
IH	Instituto Hidrográfico (Portugal)
LNEC	Laboratório Nacional de Engenharia Civil (Portugal)
NOC	National Oceanography Centre (UK)
OS	Operating System
SAR	Fast Fourier Transform
SPR	Software Problem Report
UCC	University College Cork (Ireland)
USGS	United States Geological Survey
VCM	Verification Control Matrix
VVP	Verification & Validation Plan
VTP	Validation Test Procedures
VTS	Validation Test Specifications

1 Introduction

1.1 Purpose and Scope

The objective of this document is to define the research applications developed within the Co-ReSyF project. This document is addressed to potential users that can be interested. For each application, the user will understand:

- how remote sensing and the applied method are relevant for this service
- the inputs required to run the process
- the type of products delivered as output
- the level of expertise needed to exploit this service

1.2 Document Structure

The structure of the document is as follows:

- Each chapter describes the service for the respective research applications
- Last chapter contains all the references to documents and scientific publications mentioned in other chapters

2 Bathymetry determination from SAR imagery

2.1 Overview

2.1.1 Context

Earth observation from space has become a preferred method for the monitoring of extensive coastal areas. Its low cost (per unit area) is highly rewarding when compared with traditional methods such as aerial photography or in situ surveys. In particular, the long established sound surveying methodologies to obtain the bathymetry are both time consuming and expensive. Moreover, in high energetic sandy coasts, the underwater morphology can change significantly at storm time-scales. These rapid changes cannot be measured by traditional surveys, not only for the above reasons but also because surveying vessels cannot operate in the wave shoaling and wave breaking regions under storm conditions.

Data from the European Copernicus program (Sentinel satellites) are nowadays available to the public and thus high performance platforms that can handle large volumes of data, such as the Co-ReSyF, are being developed in order to support the activities of coastal managers, national authorities and research groups in the field of Earth observation.

Very high resolution SAR imagery (with pixel size smaller than 5 metres) can nowadays be gathered by several satellite missions, allowing the above methodology to be applied with unprecedented success.

This application will provide general users with the capacity to determine the coastal bathymetry in most nearshore regions, in particular in remote areas where no other data is available or is extremely difficult to collect. Further, coastal bathymetry data is essential for coastal hazard and risk evaluation, including those associated with extreme waves, storm surges, tsunamis and others.

2.1.2 Short description of the process

The SAR-imagery bathymetry application provides the coastal bathymetry underneath a given coastal area sensed remotely by a Synthetic Aperture Radar (SAR) satellite sensor, at a given time of acquisition. The application is based on the detection of the ocean swell wavelength through the application of a 2-dimensional Fast Fourier Transform (FFT) algorithm to a SAR intensity image, which is then related to the local water depth by inverting the wave dispersion relationship (e.g., (Brusch et al. 2011; Lehner et al. 2012). The output of the algorithm consists in a Digital Elevation Model (DEM) for the target area.

2.2 User interaction

2.2.1 Input

The user should define the region of interest, and the time window for the image selection and bathymetry estimation. The possible and likely region of application is the continental shelf, bounded at the coast by the wave breaking region and at the sea by the continental shelf break.

The user shall select a single SAR image or a set of SAR images from Sentinel-1 (S1), KompSAT-5 (K5), TerraSAR-X (TSX), RadarSAT, Cosmo-SkyMed, EnviSAT or other contributing/available High-Resolution SAR images, from the Co-ReSyF catalogue, providing quicklooks to facilitate user selection of relevant images and the general region/coast of application.

Depending on the area/region of interest and the number of candidate images, the user may select ancillary wind and ocean swell data bases (hindcast or measured conditions), whose data can be used to screen the best candidate images. In particular, screening methodologies require the following physical variables: zonal (U) and meridional (V) wind components at z=10m, significant wave height, mean or peak wave period, mean wave direction.

It follows by the user the definition of the area of interest (AOI) for the bathymetry estimation. This step is performed by visual manipulation or automatically by uploading a pre-defined polygon file (e.g., KML or shapefile). The user must further choose the resolution of the final bathymetry grid and upload generic bathymetric data (e.g., from the "Emodnet" database) to roughly verify whether the AOI contains "deep water" (depth independent) points or just depth-dependent points.

An additional tidal data set or simply the tidal elevation at the time of the image acquisition (relative to a given datum) may be added by the user, in order to correct the estimated bathymetries for the observed tidal elevation.

2.2.2 Output

Pre-final and raw outputs (GeoTiff images) are produced in order to assess the results. The operator checks the bathymetry results and other output data (e.g. wave direction, wavelength) visually and possibly can annotate the image quality through software like QGIS.

Finally, a DEM (Digital Elevation Model) is generated and saved in several formats, as requested by the user (GeoTIFF, NetCDF, ASCII, Shapefile, etc.).

2.3 Required skills

To have a good use of this application, the user must be skilled in SAR imagery interpretation, coastal geomorphology, ocean wave hydrodynamics and fundamentals of ocean wave and image spectra. These skills will not only be necessary to run the application but also to interpret the estimated bathymetry results.

Further, the user must be able to set the adequate grid sizes, based on the image properties and the observed wind and ocean wave characteristics.

3 Bathymetry, benthic classification and water quality determination from optical imagery

3.1 Overview

3.1.1 Context

Optical imagery applications are in constant evolution. The range of available sensors is widening so it increases the possibilities and improves the competitiveness of already existing products.

Indeed, ten years ago, remote sensing data was quite complex to access. Satellites such as the Landsat sensors were operating since the early 1970's but due to a lack of distribution infrastructure and strict data policy, only few users could access these images and no operating systems could systematic derive products to deliver to potential users.

Since then, images became widely and freely available so it allowed multiple services to be created, using Landsat, powered by the USGS. But Landsat has a 30m spatial resolution which is problematic for bathymetry retrieval. Nevertheless, this positive dynamic was followed by the European Commission and its Copernicus program which has started the Sentinel mission: the launch of several satellites including Sentinel-2A and Sentinel-2B, twins monitoring Earth at a 10m resolution with an excellent radiometric performance and an impressively reduced revisit time.

With Sentinel-2, an image is available every 5 days so it maximizes the amount of interesting data (no cloud) to analyse over a short time period. A robust bathymetry product could be delivered every season so evolutions (sediment transport) could be seen easily, at a little cost.

3.1.2 Short description of the process

The bathymetry, benthic classification and water quality retrieval in shallow waters from optical sensors (i.e. typically between 0 and 8-10m) has to take into account several parameters that modify the light backscattered upwards the sea surface. These parameters are:

1. the water content that impacts the light travelling in the water column;
2. the light path length (so the water depth);
3. the reflection (albedo) of the seafloor (hence the benthic classification).

The method put in place is semi-automatic (at least at the start of Co-ReSyF project) – this means that successive steps have to be applied, each of them requiring a user confirmation. If the user does not confirm the validity of one step then the process is stopped and might be repeated either with a new image or with a new parametrization of the processing chain.

3.2 User interaction

3.2.1 Input

The first element to choose is the dataset taken as input data:

- For Sentinel-2 and Landat-8, the image can be directly accessed by the application without any user manipulation (no image imports). So the user only have to indicate his/her time window of interest (starting and ending date) and to select his/her area of interest (possible within a user-friendly interface)

Once these parameters are defined, the user only has to press the “Start” button and the processing will be launched on the cloud.

The last step of the processing is the averaging of all the bathymetry maps. Before this operation, the user may have to validate each of these maps in order to remove the obviously wrong data. This step will be ease thanks to the web application allowing image display and providing basic tools to keep or remove the data.

3.2.2 Output

As an output, the users will be able to download the bathymetry maps produced from each image and also the averaged one. The file format will be GeoTiff so the user can easily manipulate these files within QGIS for example.

3.3 Required skills

To run the process, the user has two interventions:

- Choose an area for the bathymetry retrieval. It means the user has the experience whether the sea bottom is distinguishable or not
- Checking visually whether the bathymetry maps are consistent or not. During the processing, some elements may alter the bathymetry retrieval. Cloud masking, water masking can fail. Also, if there is a sudden gap in the bathymetry, the user will flag the image.

To sum up, the user must have a strong background in bathymetry maps as he must know where to apply this kind of processing and also how to evaluate the quality of the outputs.

4 Vessel detection & Oil Spill Detection with SAR & Optical

4.1 Overview

4.1.1 Context

Maritime surveillance activities are traditionally carried out by patrol ships or aircrafts. However, in recent years the use of synthetic aperture radar (SAR) and optical satellite imagery has proved highly effective in ship traffic and oil spill monitoring. The capability of observing wide areas in all weather and light conditions makes SAR and optical satellite sensors the most suitable tools for maritime surveillance purposes. The goal of **the ship detection** algorithm is to identify bright objects over the darker sea surface as represented in SAR images. The **oil spill detection** can be seen as a classification or segmentation task. The purpose is to distinguish the pixels belonging to the oil slick from those representing the sea surface. The oil spills in SAR acquisitions typically appear as darker pixels. In optical imagery, the spectral signature of the investigated pixels should allow, in principle, distinguishing between sea and oil spill

For the oil spill and ship detection applications, we shall develop a tool capable of applying the necessary pre-processing steps and applying an algorithm to the imagery to detect and characterise oil spills and identify the vessel responsible for it. The output of such application shall be a single map derived from a satellite image acquired soon after the event, or a time series of maps showing the maritime traffic within and in proximity of the affected area, as well as a list of information/metadata concerning the oil spills and vessels detected. Combined use of the ship detection application and the oil spill detection algorithm could be considered to identify the vessel responsible for marine oil slicks.

4.1.2 Short description of the process

Vessel detection from SAR Imagery:

Inputs are Sentinel-1 acquisitions made available in the Co-ReSyF catalogue. Using the dedicated filters and quicklook pictures, the data search is made according to several criteria, such as: area of interest (AOI), time of acquisition, mode of acquisition, polarization, incidence angle.

Oil Spill detection from SAR and Optical imagery:

Input imagery are Sentinel-1 and Sentinel-2 acquisitions made available in the Co-ReSyF catalogue. As with vessel detection, Sentinel-1 images are chosen based on AOI, time of acquisition, mode of acquisition, polarization and incidence angle. Sentinel-2 images should be chosen based on the absence of cloud cover over the AOI.

Following the user's selection of imagery, the processing of SAR (or optical) imagery for the vessel detection (or oil spill detection) application can be summarised as follows:

1. Definition of the AOI by the user
2. Collection of suitable SAR and/or optical images
3. Satellite image pre-processing using a Co-ReSyF toolbox:

   a. SAR images calibration/Radiometric Correction
   b. Speckle filtering (SAR)
   c. Reprojection
   d. Land masking (if the images partially include lands)/clouds marking (optical)
   e. Selection and saving (in GeoTiff format) of a sub-image representing AOI
4. Visual inspection of image by the user
5. Ship detection algorithm or Oil spill detection application is applied to the GeoTiff
6. Visualisation of the results via a single map or a time series of maps.

4.2 User interaction

4.2.1 Input

The user should define AOI and time window of interest (start and end date). Following this, the user shall choose the most appropriate satellite imagery to their application. For example, SAR imagery will be preferred instead of optical when cloud coverage hinders monitoring of the region of interest. Once these parameters are defined and the appropriate imagery selected, the user may apply the necessary pre-processing steps through a dedicated and simple toolbox. Specifically, SAR images must be calibrated and undergo a despeckling filtering. Following these steps, the pre-processed images may be run through the vessel detection and/or oil spill detection applications.

4.2.2 Output

As an output, the users shall be able to download a geo-referenced map where oil slicks and the detected vessels are highlighted. The resulting map is provided as a shapefile, thus allowing the user to visualise and manipulate the output by using software such as QGIS. If continuous monitoring of an area is required, a time series of maps can be generated to monitor the evolution of the oil slick and to track vessels detected.

A list of parameters shall also be generated for each map as a .txt file. For the detected oil spills (and look-alike), this information includes day and time of the image acquisition, lat/lon coordinates of the center and farther edges of each detected object, orientation, area and perimeter of the oil slick. For each detected vessel (and false alarm) represented on the maps information provided shall include: date and time of the observation, geographical position at sea (i.e. lat/lon coordinates), heading and possibly velocity, dimensions and identification number (when the AIS data are available).

4.3 Required skills

To run the process, the user has five primary interventions:

- Choose the AOI
- Select the timeframe under examination

- Select the appropriate imagery based on mode of acquisition
- Apply the necessary pre-processing techniques via dedicated toolboxes
- Visually inspect the outputs at two points in the process:
    - To inspect the imagery after pre-processing
    - To inspect the output image(s) after the application is run

To run the applications, the user must have a keen knowledge of SAR and optical imagery interpretation. Specifically, to select the appropriate imagery, a knowledge of SAR acquisition modes is required and the influence of meteorological and oceanographic conditions on SAR data.

5 Time series processing for hyper temporal optical data analysis

5.1 Overview

5.1.1 Context

This methodology is being developed using thermal and optical imagery which is currently freely available at daily temporal resolutions, in time series extending over three years or more. The techniques have also been shown to be successful in both land (de Bie *et al.*, 2012) and ocean (e.g. the hyper-temporal precursor study conducted under the SAFI project). However, at this stage a robust study of data patterns in data with as little anthropogenic influence as possible (i.e. ocean data) is needed, to determine whether patterns evident visually in output products, are not the product of random chance. This methodology is an enhancement of that developed by de Bie *et al.* (2012) in that an additional step has been added – the statistical verification that patterns are valid patterns for interpretation.

Through its exploitation of temporal signals in each pixel, the methodology opens itself to being deployed on any time-series of image data, on the provision that it is ordered sequentially over time, and has a sufficiently number of images.

The service integrated into the Co-ReSyF platform will produce two levels of benefits to users. Firstly, users will be able to explore the temporal complexity of regions using previously untapped volumes of time-series imagery. It will effectively enable them to summarise the patterns contained in data cubes of large quantities of time-series imagery, and use the outputs to identify features of interest to explore and clarify using alternative processes. Secondly, the step nature of the algorithm allows a number of discrete process modules to be made available for users to integrate into their own algorithms, or conduct discrete processing steps, namely:

- Generation of random images based on a real image's statistical data spread,
- Deployment of an unsupervised ISODATA clustering algorithm on a data cube of images,
- Raster to polygon conversion,
- Polygon to polyline conversion,
- Raster calculation,
- Statistical analysis of images examining the spatial co-location of similar values.

5.1.2 Short description of the process

The methodology being deployed is a derivation of the LaHMa methodology developed by de Bie *et al.* (2012). Data processing for the algorithm development phase using SST data consists of the following:

1. Extraction of image data.
2. Multiple image processing to clean sequential images of raw L4 data of poor quality data, using error quality flags – also known as temporal cleaning.

3. Consolidation of the extracted seasonality data into a hyper-temporal data cube.
4. Generation of random value images for output verification.
5. Consolidation of the random images into the datacube.
6. Implementation of an unsupervised ISODATA clustering algorithm on each of the data cubes, and generation of 10-100 cluster images for each cube.
7. Extraction of cluster boundaries for both datacubes.
8. Subsequent processing to a single layered raster spatial dataset containing data on the relative regularity of boundary occurrence within pixels.
9. Statistical analysis and verification of patterning observed.

5.2 User interaction

5.2.1 Input

The process begins with the selection of an area of interest, and the parameter (and containing dataset) of interest. The third aspect of selection is the timeframe under examination, through the provision of a start and end date. Once these parameters are defined, the user only has to press the “Start” button and the processing will be launched on the cloud.

5.2.2 Output

The output provided is an image file containing pixel values of relative boundary strength/permanence, and an image file(s) containing the statistical validation values.

5.3 Required skills

To run the process, the user has four primary interventions:

- Choose the area of interest,
- Select the timeframe under examination,
- Select the parameter and dataset under examination,
- Visually inspect the outputs at three points in the process:
    - To examine whether the data have been cleaned correctly,
    - To verify that the boundary summaries have been produced correctly,
    - To verify the patterns extracted are statistically valid.

In summary, the user must have a strong background in the parameters of interest, and their extraction from satellite sensor data. In addition they should understand the implications of using unsupervised classification algorithms, and using raster to polygon conversion procedures. They must also have a background in geo-statistics so they may correctly interpret the algorithm outputs.

6 Ocean and Coastal altimetry

6.1 Overview

6.1.1 Context

Satellite altimetry over the open ocean is a mature discipline, used routinely for operational oceanography and climate studies. However, until recently, altimeter data in the coastal zone (i.e., as a guideline, within less than 50 km from the coast, but this can vary depending on the particular location) were normally flagged as bad and not used, due to issues either with the processing of the radar waveforms, or the atmospheric and geophysical corrections, or both. Significant research carried out by several groups in the last 10 years has led to the inception and development of the new field of *coastal altimetry*, aiming at removing the technical obstacles and recovering meaningful observations of sea level, significant wave height and wind in the coastal strip. This research is discussed and reviewed by the coastal altimetry community (see http://www.coastalt.eu/community) in the Coastal Altimetry Workshops (CAWs) and has resulted in the availability of dedicated processing techniques (like the ALES retracking algorithm developed by NOC), improved corrections, and new coastal altimetry datasets. The usefulness of these new data is being demonstrated at CAWs and in the peer-reviewed literature with a number of applications ranging from coastal sea level to coastal currents to extreme events such as storm surges. Moreover the reprocessed data, which have better spectral characteristics (in practice they give a 'sharper' view of the ocean surface) offer insight over the offshore ocean in all those cases where small-scale structures are present, such as sub-mesoscale filaments and slicks. In these challenging cases the availability of data reprocessed with a coastal altimetry processor may allow a better characterization of the underlying processes.

The reasons above would already be enough to justify the generation and dissemination of altimetry data with coastal altimetry algorithms, and these can also be used over challenging situations over the open ocean. The field is however receiving further impetus by two complementary facts:

- the availability of SAR mode altimetry from Sentinel-3. SAR altimetry data are intrinsically better than conventional altimetry in terms of along-track resolution and signal-to-noise ratio; those advantages are particularly beneficial in the coastal zone. The potential of SAR altimetry for oceanography has been demonstrated with data from CryoSat-2, which operates in SAR mode only over a small number of oceanic regions (see for instance Dibarboure et al., 2012; Passaro et al., 2016). The SRAL altimeter on board Sentinel-3 is now being operated in SAR mode over the global ocean.

- the synergies between the multi-parameter measurements taken by different instruments aboard the Sentinel constellation of satellites, in particular the complementary views of the ocean surface gathered from SAR on Sentinel-1, Multispectral visible/infrared from MSI on

Sentinel-2, SAR altimetry from SRAL, ocean colour from OLCI and SST from SLSTR on Sentinel-3.

The Ocean and Coastal Altimetry application in Co-ReSyF enables users to fully exploit the potential of altimetry from conventional instruments and SAR altimetry from Sentinel-3 by allowing them easy, intuitive, efficient access to data reprocessed with improved techniques. At the same time, it enables multi-parameter studies in synergy with the other proposed applications.

6.1.2 Short description of the process

The selected altimeter data at high rate (20 Hz, corresponding to 360 m along-track) will be retracked with the state-of-the art ALES retracker (Passaro et al., 2014) if in conventional (pulse-limited) mode, or with an extension of ALES to the SAR waveform if in SAR (delay-Doppler) mode. This will yield estimates of (uncorrected) range, significant wave height and wind speed; the latter two variables can be directly used in applications. Then the latest corrections, orbits and mean sea surface will be retrieved from the RADS archive (Scharroo et al., 2012) where these are continuously updated, and applied to the uncorrected range to convert it into Sea Surface Height Anomalies (SSHA) application to ocean dynamics and sea level studies.

6.2 User interaction

6.2.1 Input

Selection of altimeter data is not straightforward and necessitates some explanation. Altimeter data are along-track, i.e. they are essentially 1-D measurements along the ground track (called a ‘pass’) of the satellite. Passes are numbered: for missions that adopt a repeat-orbit pattern, i.e. when each ground pass is repeated after a period of few days called a ‘cycle’, the numbering is the order of the passes within the cycle; for missions that do not repeat exactly the same ground passes, such as CryoSat-2, the numbering is based on pseudo-cycles or sub-cycles and nicely codified in the RADS archive. Some altimeter missions also went through different ‘phases’, i.e. the orbit patterns were changed (for instance from a repeat phase to a non-repeat phase). The application needs as input the specification of the satellite mission and phase, the pass or passes and any longitude or latitude limits within a given pass, as well as the desired cycles (which delimit the time). The user can either specify one or more of those quantities directly (which is extremely useful for some applications, for instance when the user wants a time series of all the repeated transits of the altimeter over the same pass, i.e. the same ground track), or use a mission/cycle/pass database which the user interrogates simply by specifying the time interval required and the geographical domain required. Selection of the geographical domain should be made possible in three ways:

- Simple Lat/Lon extremes (box)
- Input of a polygon in ASCII or .kml format
- Selection of a region from a list of preset regions (Mediterranean, North Sea, Bay of Biscay, Catalan Coast, etc), with the possibility of saving more presets.

Once the region and time selection are carried out the application locates the matching passes and plots their tracks on a map allowing the user a further sub-selection. The result of the selection process is a structure of arrays [mission, phase, cycle, pass, [latitude_minimum, latitude_maximum]] that goes to the processor for processing. The user can further specify:

- The 'richness' of the output, i.e. if the user just wants time, longitude, latitude (which are always output) plus one variable (for instance the SSHA or SWH), or more variables, see 6.2.2. below. Simple default output options are available for less-expert users.
- Which corrections should/should not be applied in the computation of SSHA (if SSHA is an output variable). Default options (including a 'Co-ReSyF recommended' set) are available for less-expert users.

6.2.2 Output

The output provided by the application is a NetCDF file that in its simplest form contains time, longitude, latitude (which are always output) plus one variable computed by the processor (such as for instance SSHA), but it can be more complex and include corrections, original and fitted waveforms, fields from the original data records (such as the SSHA computed with standard algorithms), additional fields such as distance from coast or retracking misfit.

6.3 Required skills

Non-expert users only knowing the basics of altimetry should be able to use the application in very little time thanks to the use of the mission/cycle/pass database (which only requires them to specify a time window), the preset regions, and the default options for the correction. Documentation with examples and case studies will guide the users towards acquiring more familiarity with the mission/date/region selection and with the option of the corrections and the output. Expert users will be able to exploit the richness of information in the dataset in full, including comparing the dedicated coastal altimetry results with results from the conventional processor.

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