COASTAL CHANGE FROM SPACE
Validation in Québec

Table of contents

List of figures

1. Introduction

The European Space Agency (ESA) has funded the "Coastal Change from Space" consortium to explore the feasibility of producing the information needed by the end-users in Quebec, R. Ireland, UK and Spain. This document presents a synthesis of the validation analysis of the satellite-derived products developed by Argans for 3 coastal sites in Quebec. The objective of this validation document is to assess the new products capacity to provide sufficient information to end users for application in the current monitoring practices (*i.e.* evaluation of products).

2. Methodology

2.1. Pilot sites

The St-Lawrence coastline is characterized by many types of coastal environment such as Maritime march, beach terrace, coastal spire, moving cliffs, rocky cliffs and artificial coastline (definition can be found in Drejza et al 2015). Unconsolidated, low-lying coasts consisting of salt marshes, sandy barrier islands and beaches occur mainly along the St. Lawrence estuary and western shores of the Gulf of St. Lawrence (Quebec, Prince Edward Island and New Brunswick) and on the Îles de la Madeleine, as well as along the Bay of Fundy, especially at its head.

Figure 1 shows the validation sites. All these sites combined represent a total observation extent of 112km of Longue-Pointe-de-Mingan, 163km of Manicouagan, 183km at Point-aux-Loups.

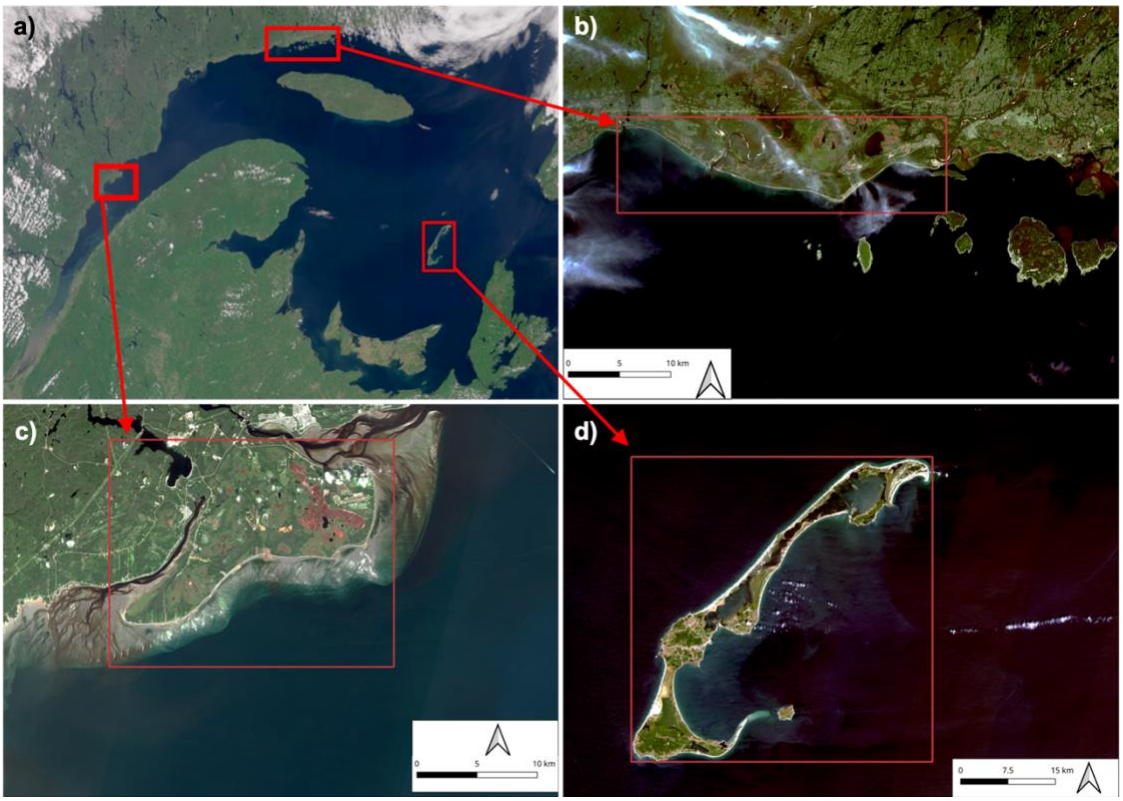


Figure 1. a) Validation sites in the Gulf of St. Lawrence: b) Longue-Pointe-de-Mingan, c) Manicouagan, d) Pointe-aux-Loups

Study site #1: For the Longue-Pointe-de-Mingan area of interest, in the last years this sector has been extensively studied due to the proximity of the main road of the North Shore (Drejza et al. 2015). This road is the only access to the north of the Minganie Regional county municipality. The average historical erosion rate for the case site is -1.97 m/year between 1948 and 2005. Between 200-2017 mean annual rate = -1.39 m/y. This case study site includes two villages namely Rivière-Saint-Jean (in the estuary of the eponymous river) and Longue-Pointe-de-Mingan. Route 138 is in this area the only link between communities, thus, a break in service would prevent any movement. The occupation of the territory is limited to a thin coastal fringe and in several sectors, the road is the only built infrastructure.

Study site #2: On the second study sites, the coastal sector of the Manicouagan Peninsula - Upper North Shore, has for many years experienced major declines in its shoreline due to erosion and gravitational soil. All this problem is widely documented in Dubois et al. (2005). These phenomena ultimately threaten the integrity of the properties that are implanted there, first at the level of land and then residences themselves. Public infrastructures are also threatened.

Study site #3: Coastal erosion in Magdalen Island is a major issue for communities and public infrastructure. In a climate change context, less sea ice and more coastal submersion will increase the dynamics of erosion. Located in the centre of the Gulf of St. Lawrence, the Îles de la Madeleine is an archipelago of 10 islands (total area about 190 km^2) with a population of approximately 12 600. The living area of the archipelago is restricted, with the maximum width of rocky outcrops not exceeding 10 km and their central part often being high and steep. Tourism is a key component of the local economy. The Îles de la Madeleine are vulnerable to coastal hazards, and the archipelago is particularly sensitive to erosion. Coastal infrastructure on the Îles de la Madeleine is threatened by shoreline retreat at several sites, including the main road network of the archipelago and the sewage purification ponds of the main community.

2.2. Satellite-derived products

- Waterlines from optical sensors (SDWL): instantaneous interface between water and sand in the moment of the image.
- Shorelines from optical sensors (SDSL): waterlines corrected to represent a certain water level (e.g. Mean Sea Level, Highest Astronomical Tide and Lowest Astronomical Tide).
- Coastal bathymetry (SDB): Shallow waters depths obtained from optical sensors.
- Habitat maps: This product is containing a time stamped Land-Use Land-Cover of the coastal zone (including backshore (first few meters of the backshore), foreshore and nearshore).

The type and number of products validated for each study site varies significantly as shown in Table 1.

Table 1. Type and number of products per validation site evaluated

Type	EO products naming	Mingan	Manicouagan	Pointe aux Loup
Waterlines	CE_ARG_**area**_L2_1D_OB_WL_**sensor_date**.shp	**254**	**233**	**82**
Waterlines	CE_SAT_**area**_L2_1D_OB_WL_S1_**date**.shp	**342**	**213**	**224**
Shorelines	CE_ARG_**area**_L2_1D_DB_SL_HHWS_**date**.shp	**242**	**331**	**18**
Shorelines	CE_ARG_**area**_L2_1D_DB_SL_MSL_**date**.shp	**242**	**331**	**18**
Shorelines	CE_ARG_**area**_L2_1D_DB_SL_HHW_**date**.shp	**242**	**331**	**18**
	CE_ARG_**area**_L2_1D_DB_SL_LLWS_**date**.shp	**242**	**331**	**18**
	CE_ARG_**area**_L2_1D_DB_SL_LLW_**date**.shp	**242**	**331**	**18**
Topo-Bathy	CE_ARG_**area**_L2_3D_BT_SDB_**sensor_date**.tif	**2**	**10**	**9**
LULC	CE_ARG_**area**_L3_2D_FB_LULC_**sensor_date_date**.tif	**0**	**2**	**2**

L8: Landsat 8; S2: Sentinel 2; LULC: Land Use & Land Cover;

2.3. Ancillary data

SHORELINES AND WATERLINES

Waterline measurements were obtained from axis cameras deployed along the coast of the Manicouagan and Longue-Pointe-de-Mingan AOI. A calibration procedure for the orthorectification of the video frame was performed using a digital GPS and multiple ground control points. Using this calibration method (fully detailed in Didier et al. 2017), it is possible to draw a waterline (i.e. instantaneous limits between land and water) and project on a map.

LIDAR topography data obtained from in-situ measurements were used to validate waterlines and shorelines. LIDAR data (provided by our partner Université du Québec à Rimouski) was processed to extract the 0m elevation isobath. This ancillary data is used to validate the shoreline. (LIDAR: vertical precision 0.002m; horizontal precision 0.04m)

BATHYMETRY

Bathymetry data was obtained from the government opendata platform from the Canadian hydrographic service. The data freely available are non-navigational data (NONNA) at 10 meters of spatial resolution (data provided by the Canadian Hydrographic Service (CHS) of the Department of Fisheries and Oceans (DFO). Although it is a LIDAR and multibeam survey, it could contain erroneous data. Data available are limited to few tiles especially in the north of our area of interest in the Magdalen Island.

2.4. Match-up database

SHORELINES

Matchup analysis were carried out using satellite products obtained in the dates closest to measurement days.

To obtain pairs of data to be compared, we drew the measured and satellite derived shoreline (SDS) and we identified the intersection points of both shorelines with cross-shore transects placed along the coast (Figure 2). Then the distance between in-situ shoreline and SDS is calculated.

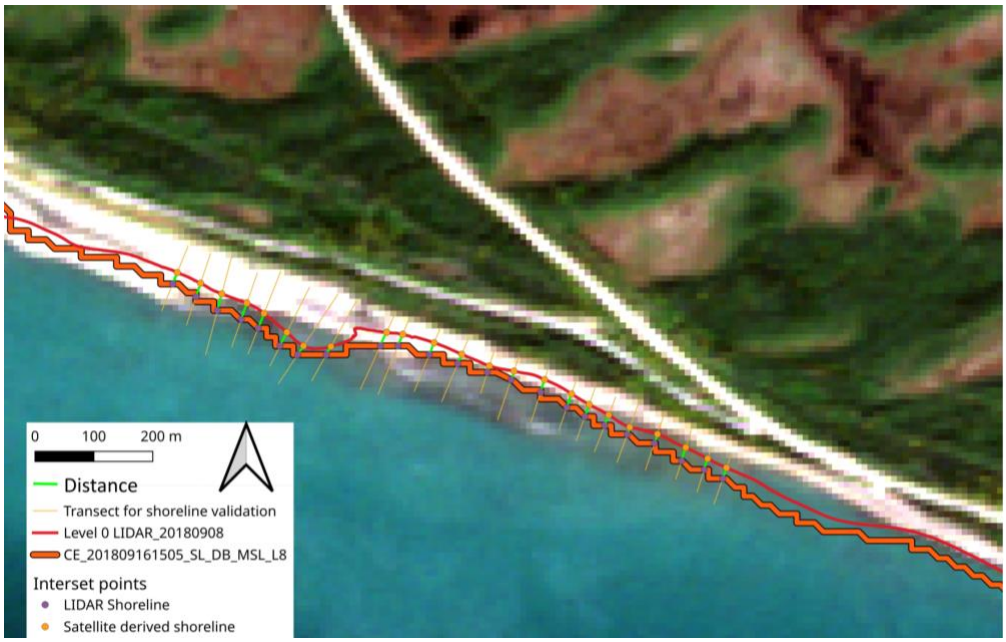


Figure 2. Example of intersecting points and distance (green line) between in-situ measured shoreline (red line) and satellite-based shoreline (orange line).

WATERLINES

The temporal match between waterlines obtained from ancillary data and SDW was validated using the closest (±1 day) data. Details on the in-situ waterline generated for validation are available in the ancillary section.

BATHYMETRY

Satellite derived Bathy-Morpho-Terrain-Model (SD-BM-TM) metadata are not completed the year of acquisition and the type of technology is not well documented.

2.5. Metric calculation

For the shoreline validation, the absolute error was calculated as the cross-shore distance between measured shoreline and SDSL. Habitat maps were validated qualitatively since no ancillary data were available.

For the SD-BM-TM the root mean square error and the Bias was calculated between the NONNA-10 and satellite derived estimation. Since the accuracy and the date of acquisition of the ancillary data is missing error should be carefully taken into account.

The RMSE and the bias in percent are calculated using the following equation:

$$RMSE = \sqrt{\overline{(f - o)}^{2}}$$

$$Bias = 100 * [\, sum(\, f - o \,) \,/\, sum(\, o \,) \,]$$

Where f is the forecasts (expected values or unknown) and o is the observed values.

3. Validation

3.1. Visual evaluation

Both ancillary (in-situ) and satellite derived data were assessed to ensure the consistency of the initial dataset used for validation.

SHORELINES

Visual evaluation of the satellite derived shoreline produced for the Quebec area of interest was carried out to assess the coherence with the ground truth. In several places, underwater or on-shore features are captured and lead to outliers (Figure 3). These features should be manually deleted. No quality control flags are available, adding flags to the shoreline would be an added value to select a constant shoreline.

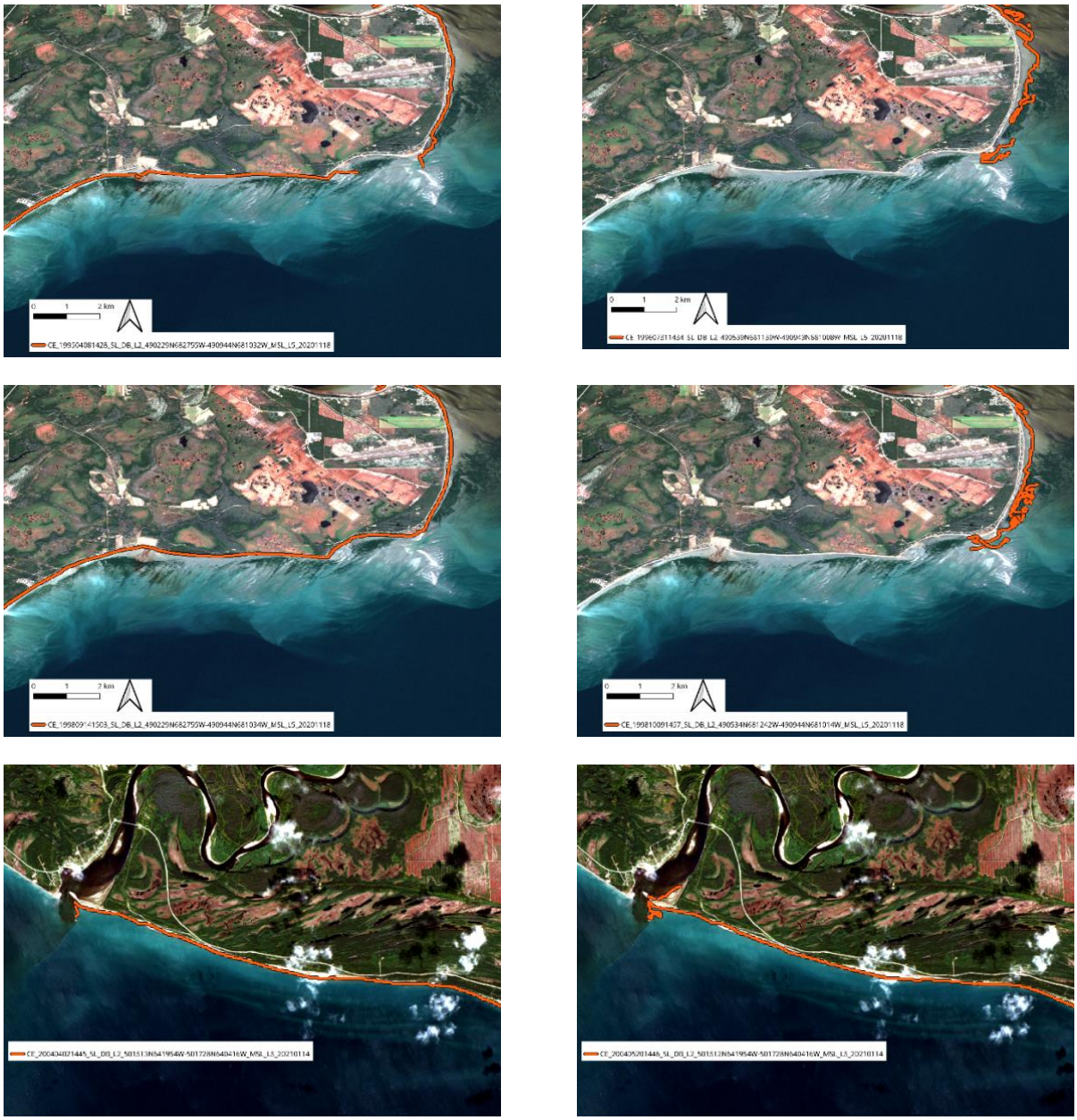


Figure 3. Examples of inconsistencies verified in satellite-derived shorelines in two of the pilot sites: Pointe-aux-Outardes (Manicouagan) et Longue-Pointe-de-Mingan.

WATERLINES (PROXY-BASED: SEA-LAND INTERFACE)

Satellite-derived waterlines (SDW) were defined as the instantaneous interface between sea and land by optical (SDW-opt) and radar (SDW-sar) sensors. Visual assessment of the SDW shows numerous inconsistencies due to underwater features, clouds, and non-homogenous bottom type (Figure 4).

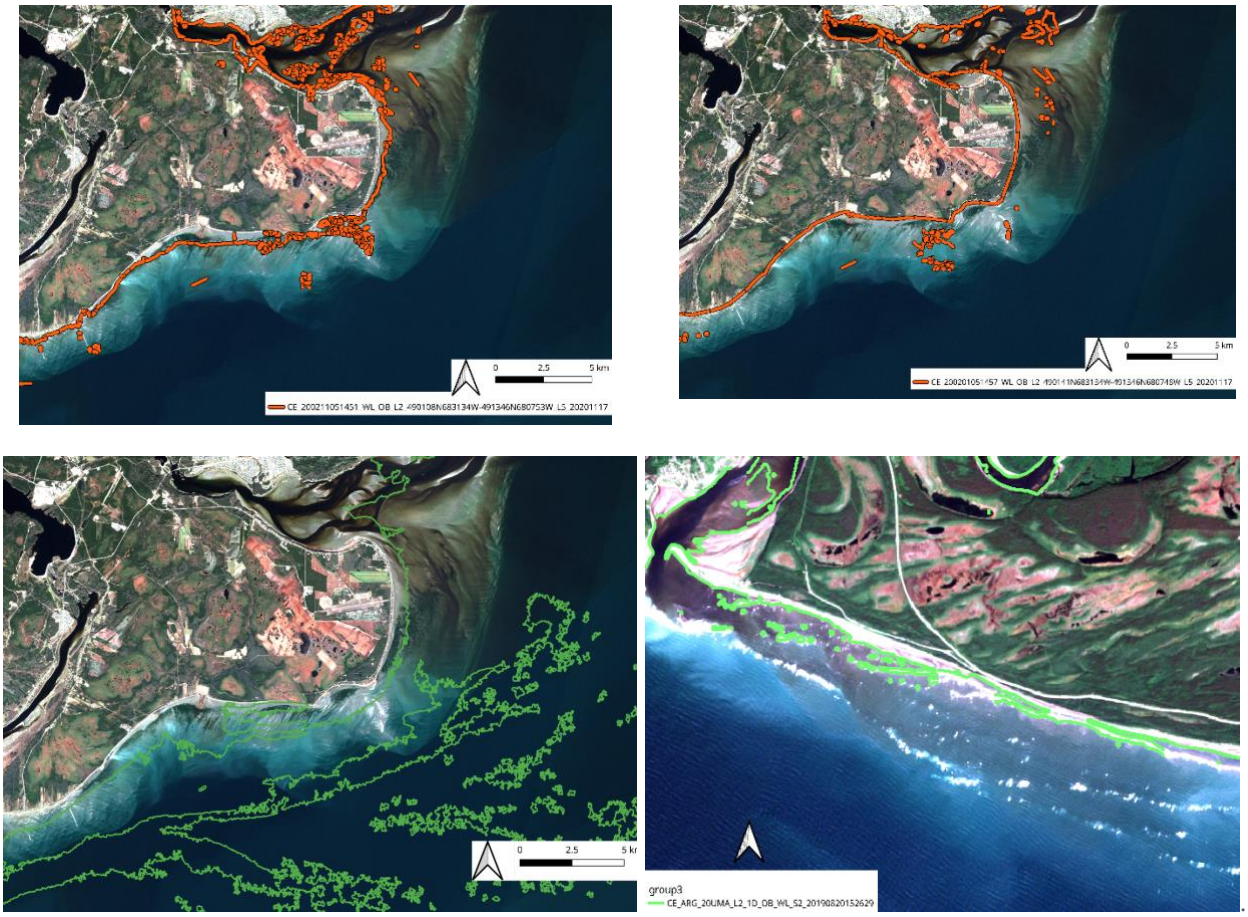


Figure 4. Examples of inconsistencies verified in satellite-derived waterlines from optical sensors (SDW-opt) in both pilot sites: Manicouagan (Top panels). Bottom panel, satellite-derived waterlines from radar sensors (SDW-sar). (Image Sentinel 2 true color 20131027).

Because of those inconsistencies, manual edition of the SDW is necessary before any analyses and validation. The quality control indexes available in final EO products allow the automatic identification of those sections of shorelines that may represent erroneous information (Figure 5).

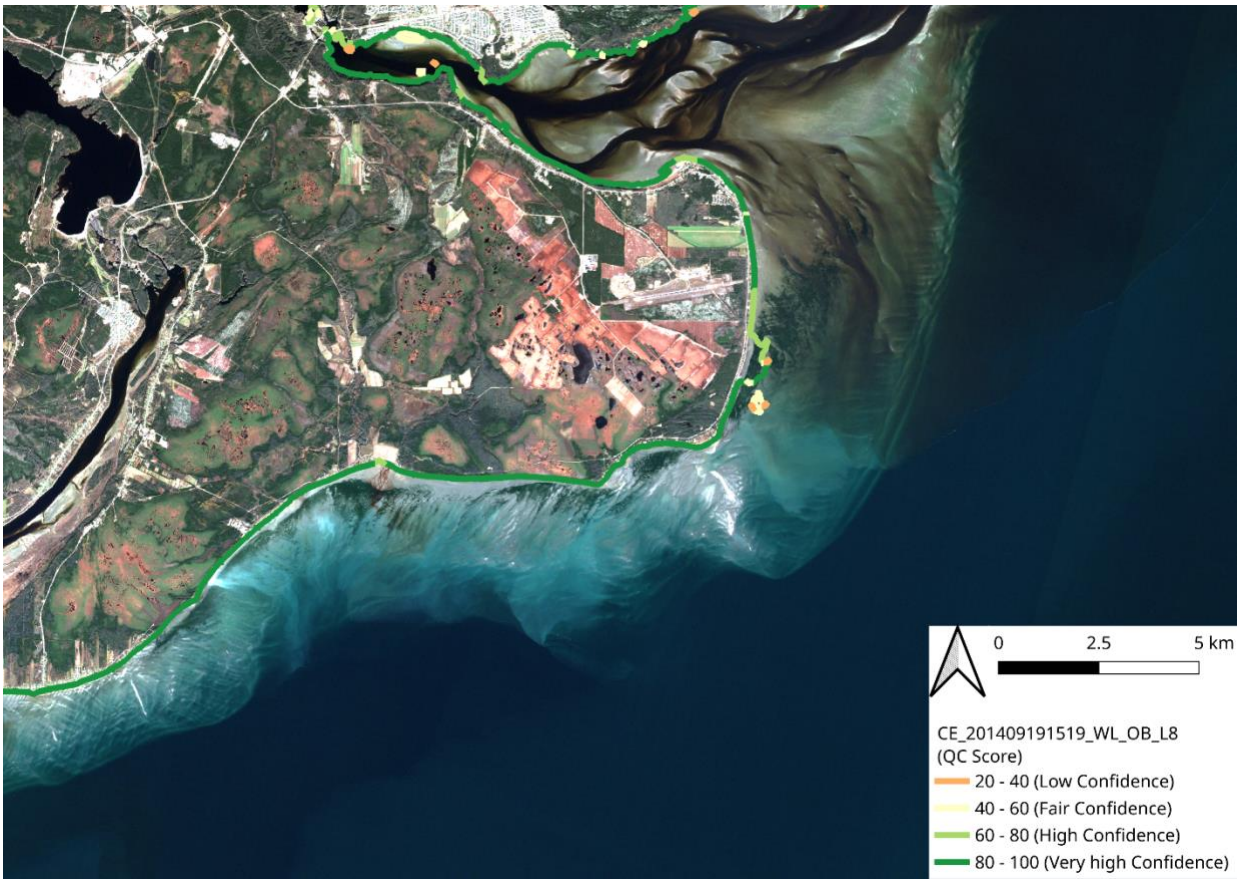


Figure 5. Example of the quality control score attributed to different stretches of a waterline in Manicouagan (QC).

Despite these inconsistencies and after manually editing the shoreline/waterline the availability of a long archives of earth observation data allows to assess changes in the beach/shore position (Figure 6).

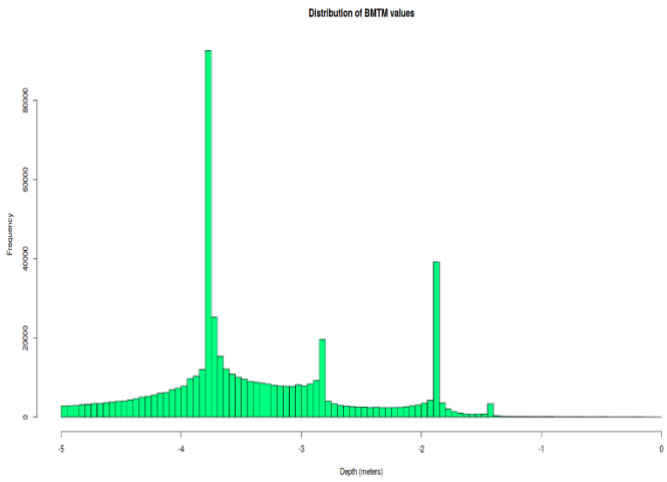
Figure 6. Time series evolution between 1995 (blue line) and 2019 (red line) waterline on Longue-pointe-de-Mingan study site.

BATHYMETRY (SATELLITE DERIVED BATHY-MORPHO-TERRAIN-MODEL - SD-BM-TM)

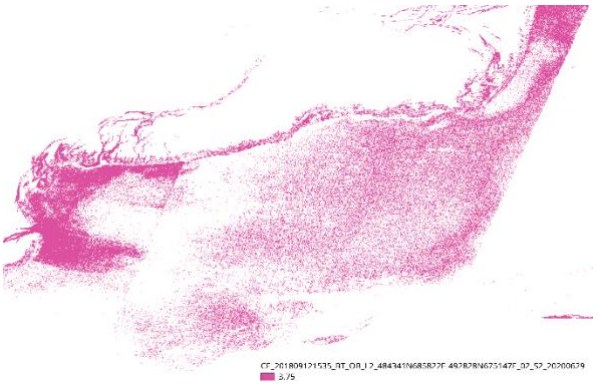
The sediment and organic matter in suspension in the water column affect the satellite derived bathymetry. In the St-Lawrence estuary, high absorbing and scattering elements in the water columns significantly limit the bottom detection with satellite imagery.

In the Manicouagan AOI and the river st jean AOI shows numerous outlayers and inconsistent depth values were noticed. These incoherence are mainly due to suspended sediment coming from the adjacent rivers and color dissolved organic matter in the water columns (Figure 7 and Figure 8).

a)



b)



c)

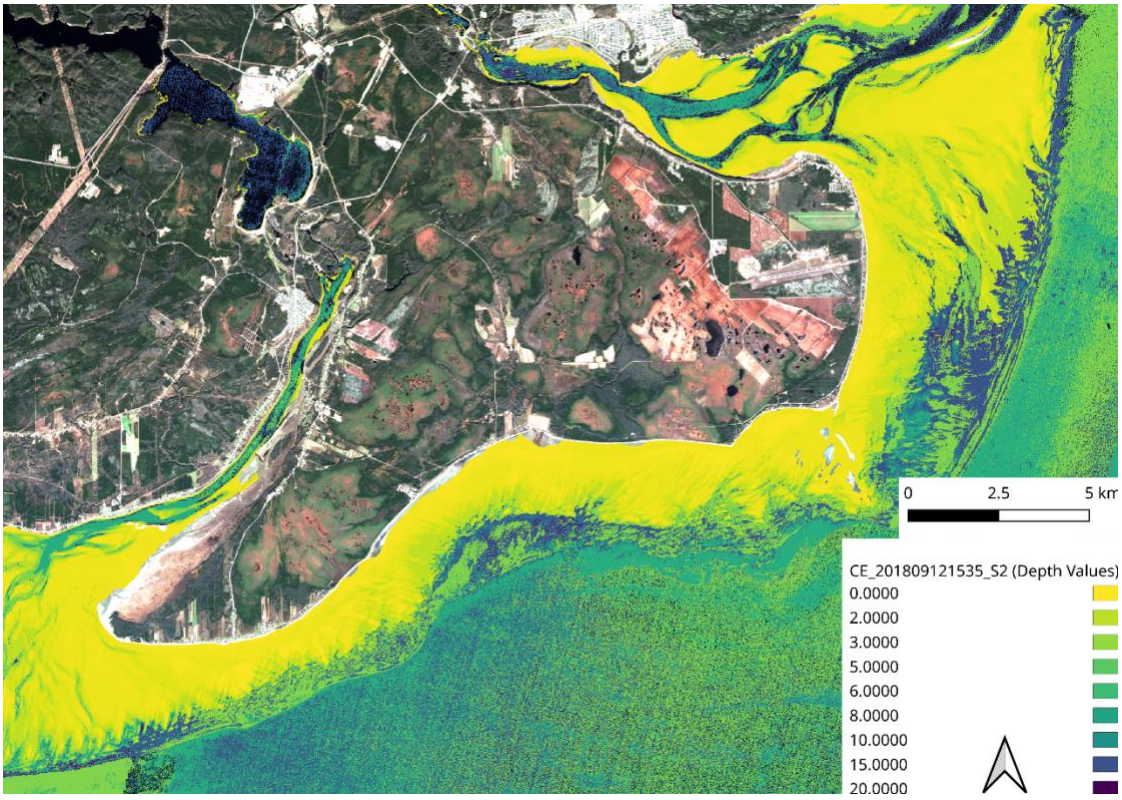


Figure 7. Example of SD-BM-TM from the Manicouagan area. a) Depth values histogram, some incoherent data appears highly represented. b) repartition of inconsistent pixels with at 3.75 m depth. c) SD-BM-TM.

a) **b)**

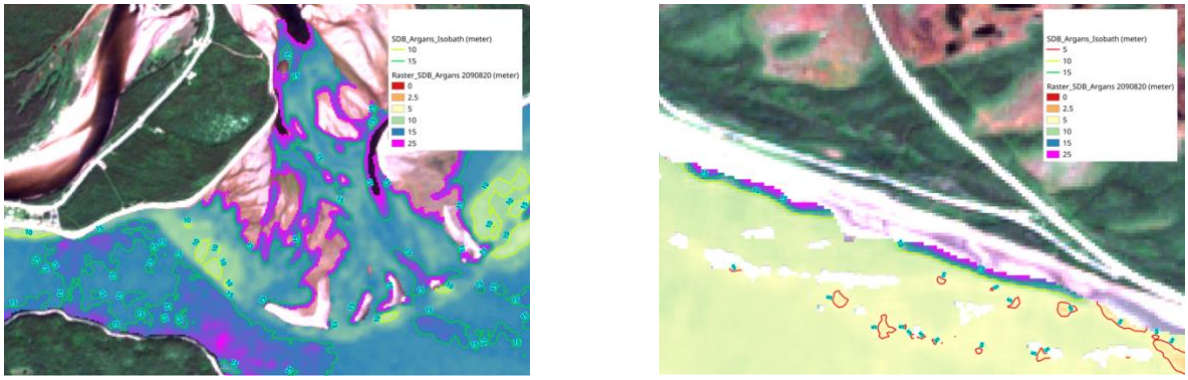


Figure 8. Example of SD-BM-TM in Manicouagan area. a) Incoherent data on the La Romaine river's mouth. b) incoherent high depth values data near the shore

Knowing these inconsistencies, we focus our validation on areas with clearest water. We assess the reliability of the satellite derived bathy-morpho-terrain-model (SD-BM-TM) on the Pointe-aux-Loup (Magdalen Island) area. (Figure 9).

a) **b)**

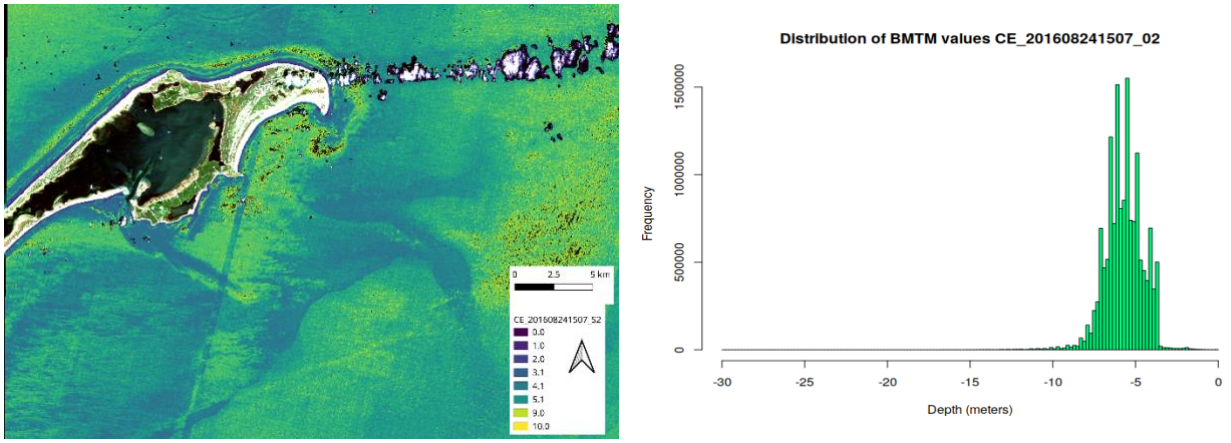


Figure 9. a) Magdalen Island satellite derived bathymetry. b) Data distribution and frequency for the satellite derived bathymetry (image: Sentinel 2 20160824).

3.2. Analysis and Interpretation

SHORELINES

The cross-shore distance between measured and satellite derived shorelines was estimated as presented in Figure 10. Example of the absolute error resultant from Landsat-8 image in Pointe-de-Mingan AOI is presented in Figure 11. For most transects (apart from transects 3 and 4), the cross-shore distance between measured and satellite derived shoreline was less than 30 m, the typical resolution of Landsat 8 images. In this case, the absolute mean distance between the two lines is 22.6 m.

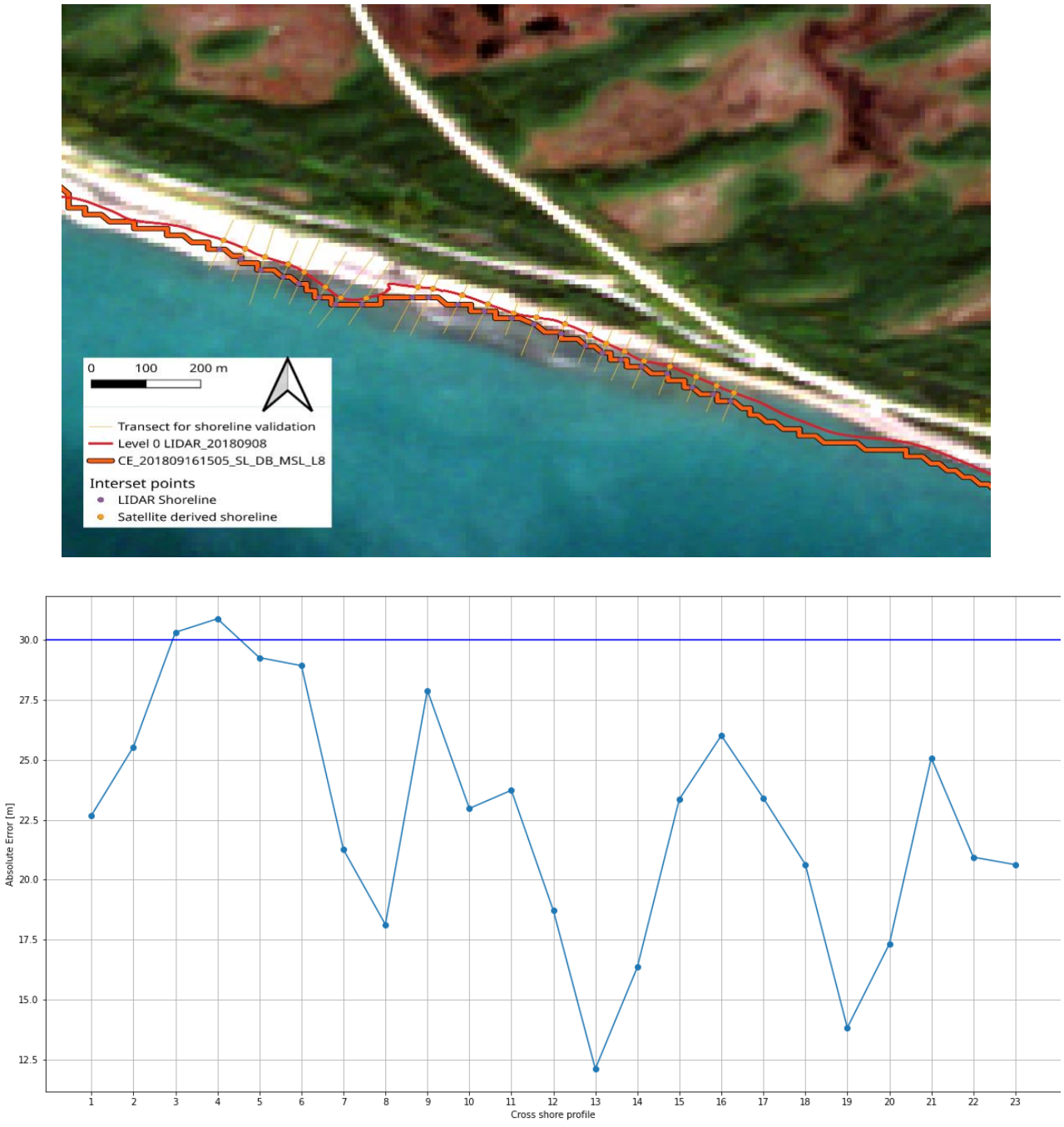


Figure 10. Absolute error of SDS from Landsat 8 image along the cross-shore transects in Longue-Pointe-de-Mingan. Blue line is the 30 m Landsat 8 pixels size.

SHORELINE TIMESERIES

On each selected survey marks provided by UQAR-LDGZIC, we drew a cross shore profile to get the intersection between profile and the SDS or SDW. The survey mark is used as a reference to calculate the distance between each intersection between the shoreline and the cross-shore profile. For the time series of the shoreline evolution, we used the first year of SDL as a reference and we subtract each SDL to the reference in order to assess the displacement (negative values: erosion, positive values: accretion). For

example, the time series evolution suggests a trend of erosion at station STN_13394 and a trend for accretion at STN_10092 in Figure 11.

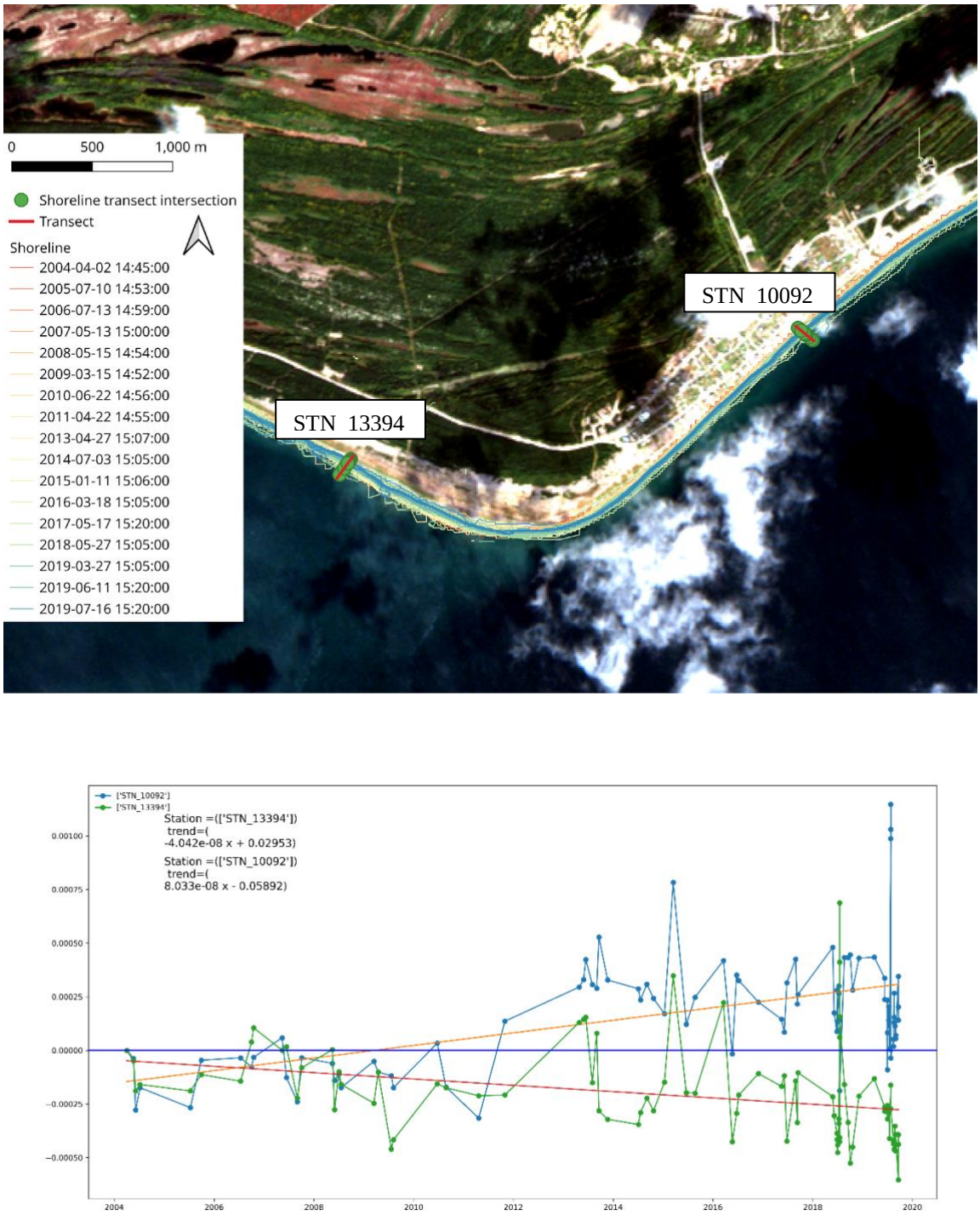


Figure 11. Top: Shorelines evolution from 2004-2019 and location of 2 stations (STN_13394, STN_10092). Bottom: Distance from the reference survey marks (UQAR-LDGZIC) of the whole time series of the shoreline at Mean Sea Level (MSL) for station STN_10092 (blue) and STN_13394 (green) and their respective trend lines (orange and red). AOI - Longue-pointe-de-Mingan.

WATERLINES

Figure 12 presents examples of the error verified for SDSL obtained from Landsat 8, of Pointe-aux-Outardes, in Manicouagan area of interest. Again, the distance between validation data and SDW is below pixel resolution.

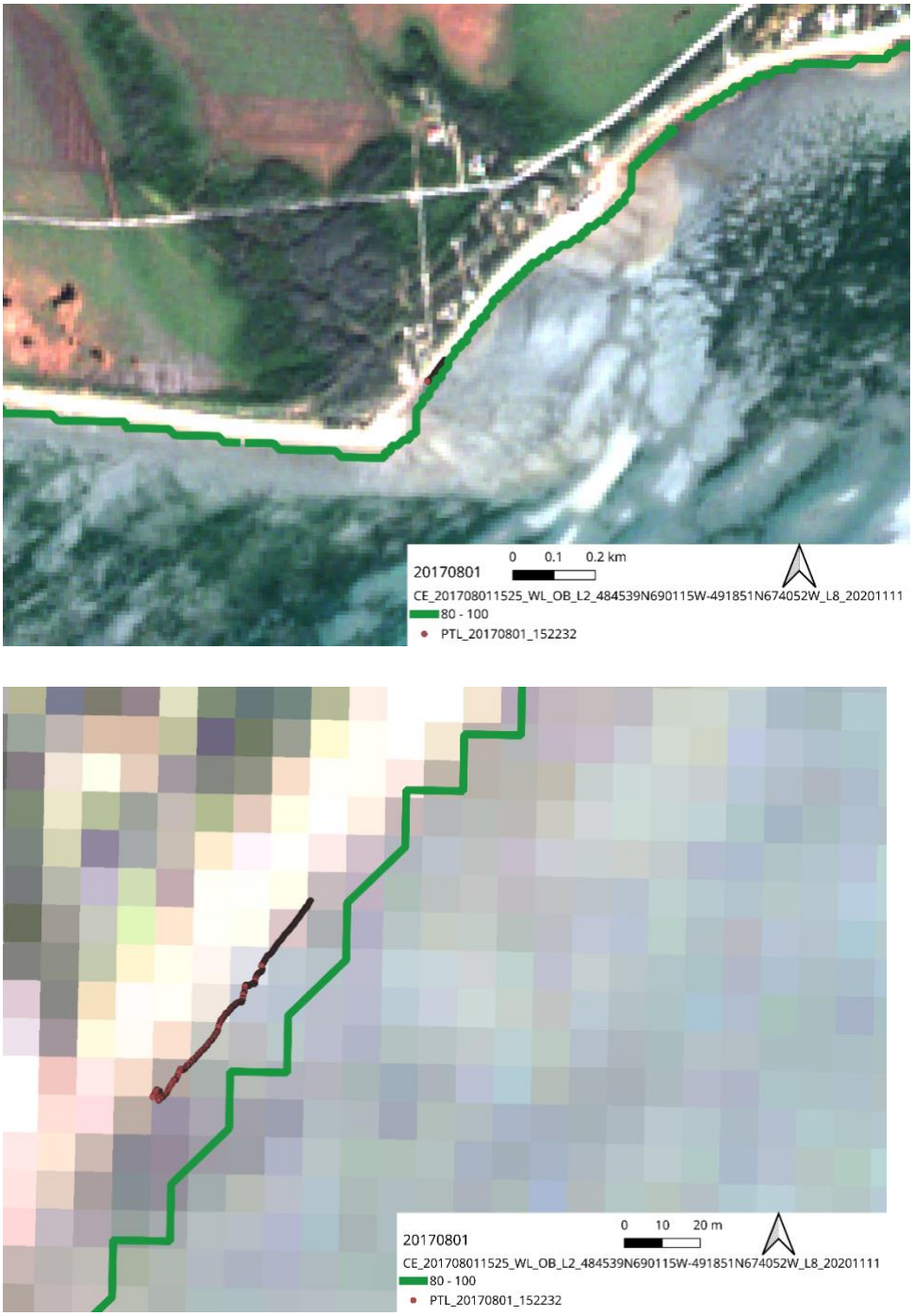


Figure 12. Validation of the SDW from Landsat 8 image with in-situ waterline on the Pointe-aux-Outardes in Manicouagan area. Top panel is a view of the large validation site. Bottom panel is the zoom in of the validation area.

Figure 13 shows the distance calculated between each points of the in-situ measurement and the matching SDW. The mean distance between in-situ and SDW is 17 meters which is less than the standard pixel size of Landsat8.

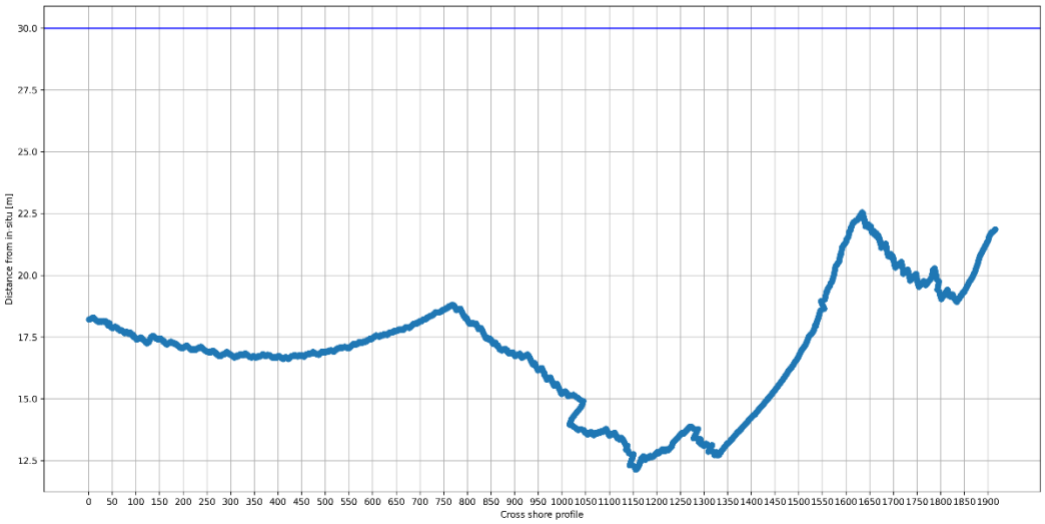


Figure 13. Distance between the validation waterline and the SDW. The distance is calculated using each points of the in-situ data. The top blue line represents the 30 m resolution of Landsat 8 pixels.

BATHYMETRY

The assessment of the satellite derived bathy-morpho-terrain-model (SD-BM-TM) accuracy is intricate for our ROIs. First, the validation metadata is incomplete and the year of the acquisition is unknown. Second, the Magdalen Island is a sandy region with frequent storms and strong currents, leading to large displacement of sand banks. For these reasons, a quantitative comparison with in-situ NONNA-10 datasets is not possible. However, we provide a qualitative comparison to assess the "potential accuracy" of the SD-BM-TM products. It is thus possible to qualitatively assess the locations variability of shoals and sand banks through the years or after major climatic events.

Figure 14 shows the SD-BM-TM evolution in 2017 in comparison to the reference year 2016 (2017 minus 2016). Negative values (orange and red) show larger differences in the 2017 SD-BM-TM, highlighting shallower regions. A potential explanation of this discrepancy is an extreme storm in December 2016, leading to a possible sand remobilization, transport and deposition.

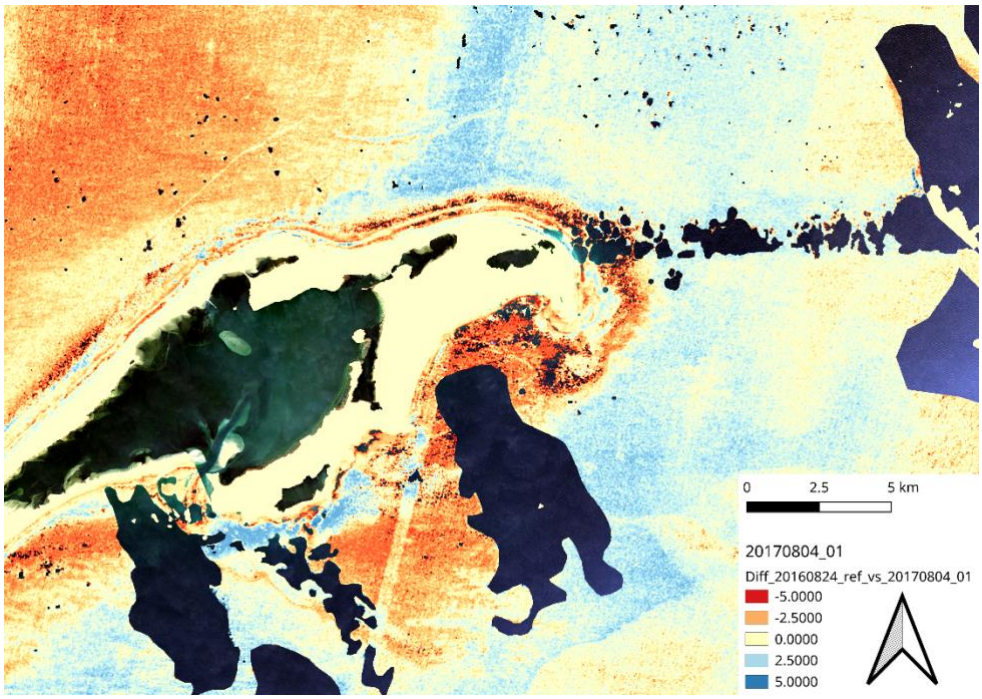


Figure 14. SD-BM-TM difference between 2017 and 2016 for the north of Magdalen Island peninsula.

Figure 15 shows the coverage of the NONNA-10 validation data. Sandwaves, ripples and bottom heterogeneity are visible on the north of the survey.

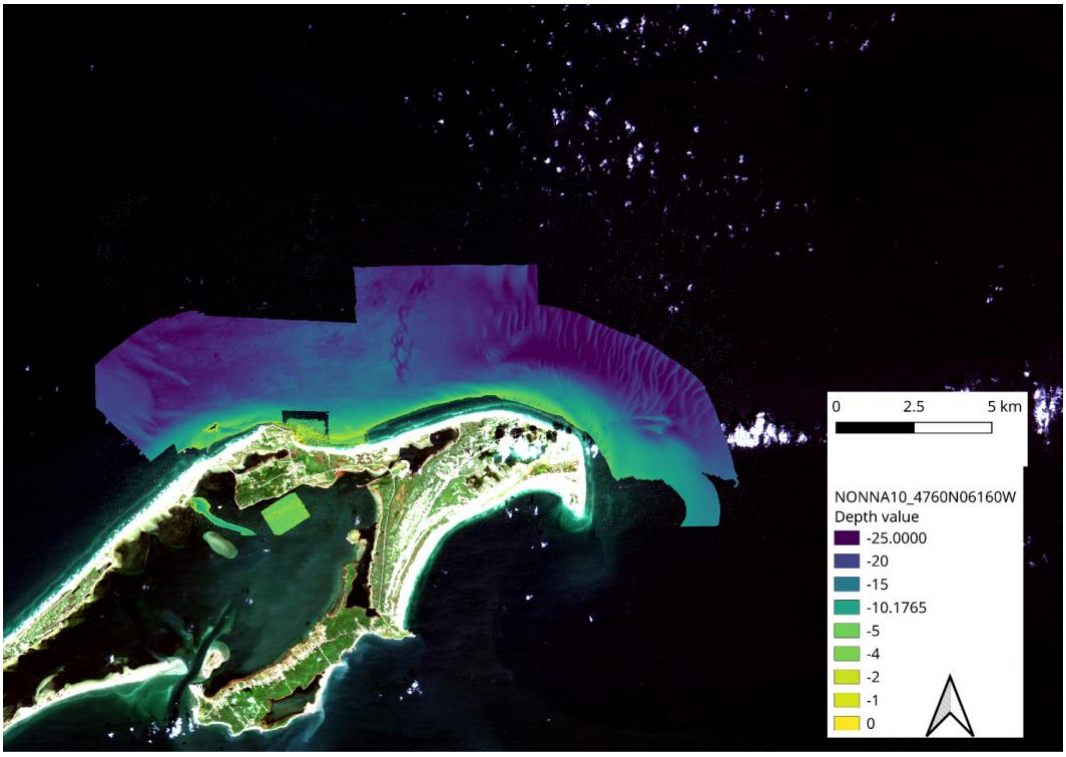


Figure 15. NONNA-10 data coverage on the north of the Magdalen Island (Gulf of St-Lawrence, QC, CANADA).

Figure 16 shows the pixels-by-pixels comparison between the NONNA-10 and SD-BM-TM for the whole area of interest covered by observations. The SD-BM-TM shows a threshold around 10 m deep due to the limit of the light penetration in the water. In the 0-10m depth range, we found a RMSE of 1.88 m and a bias of less than 10%.

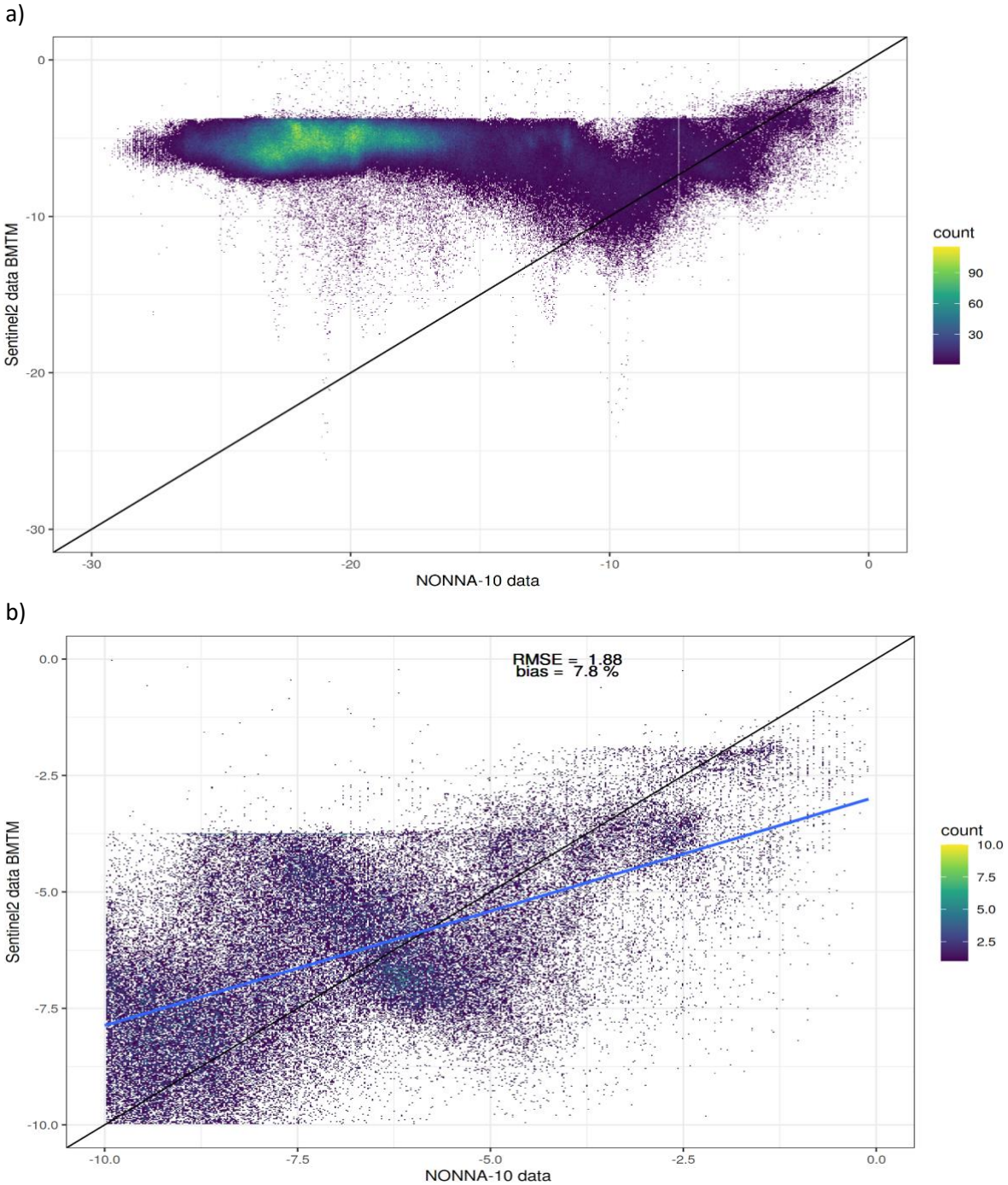


Figure 16. Scatter plot of the NONNA-10 vs SD-BM-TM 20160824 for a) the range of the depth between 0 and -30m and b) for the range between 0 to -10 m.

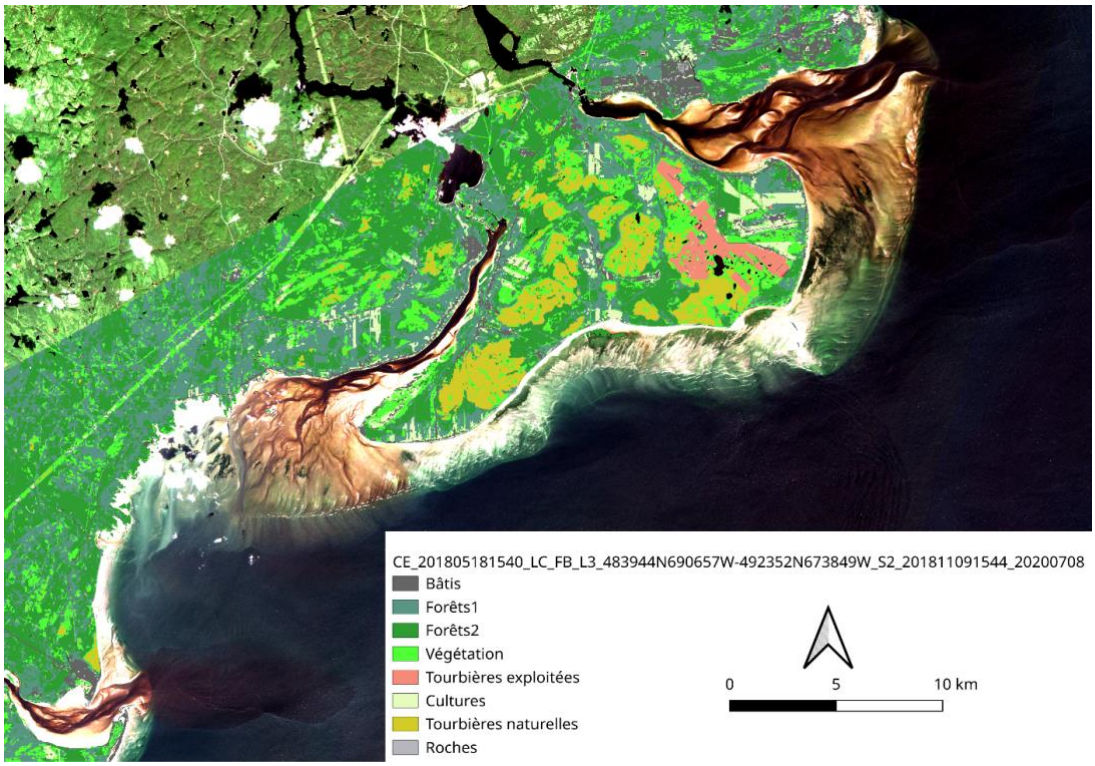
HABITAT MAPS

Near shore land-use and land cover classification is a proper product to assess the impact of the coastal erosion on shore habitats. The loss or gain of land is a critical knowledge to end-users in coastal management (Table 2). The habitat maps provided by the contractors only cover two years of data and it is not possible to assess the long-term impact on the habitat change or its evolution. The maps can yet be considered as the initial condition for the land coverage monitoring, providing a crucial starting point (Figure 17).

Table 2. Area by classes of the Land cover for the Manicouagan area of interest (Pointe-aux-Outardes).

Classes	Area in km² year 2018	Area in km² year 2019	Changes in km² (negative: loss) (positive: gain)
Built	41.9465	52.7057	10.76
Forest 1	295.1262	238.1365	-56.99
Forest 2	587.4065	579.8032	-7.60
Vegetated	161.329	203.2483	41.92
Natural peat bog	37.2795	48.665	11.39
Exploited peat bog	11.1583	11.2729	0.11
Rocks	5.0715	7.282	2.21
Crops	22.2869	14.0174	-8.27

a)



b)

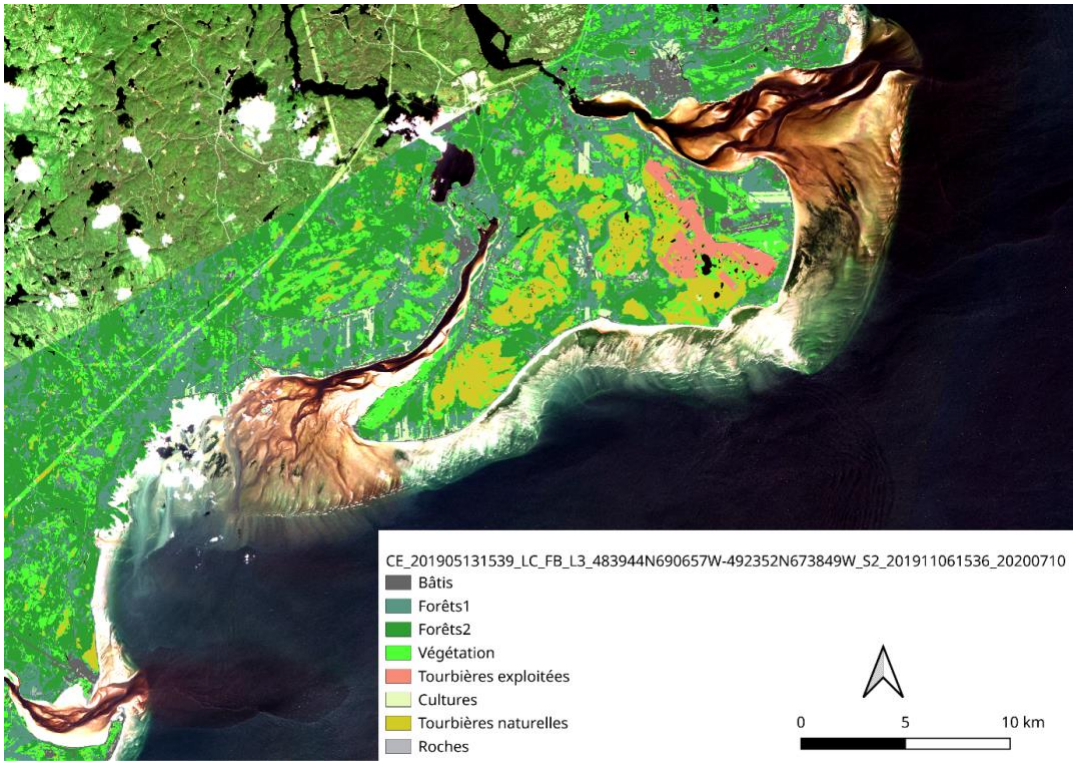
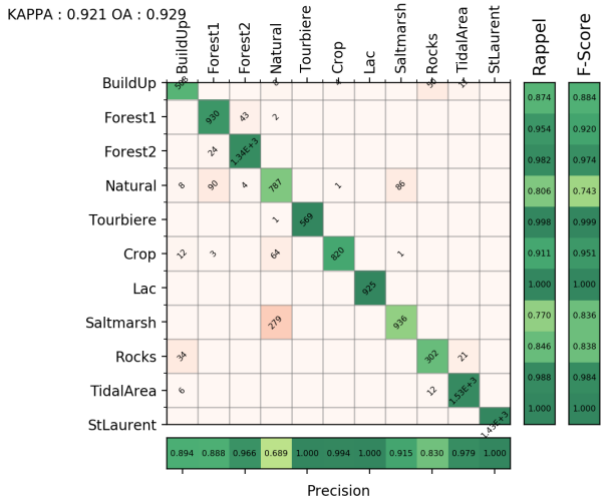


Figure 17. Habitat maps for the Manicouagan area of interest a) in 2018 and b) in 2019.

Figure 18 shows the confusion matrix for the classification models for the year 2018 and 2019 respectively. Kappa coefficient is higher than 0.90 for the two years. The kappa statistic represents the accuracy of the

classification based on a selection of the training samples. A cross validation using an independent set of samples should be done.

a)



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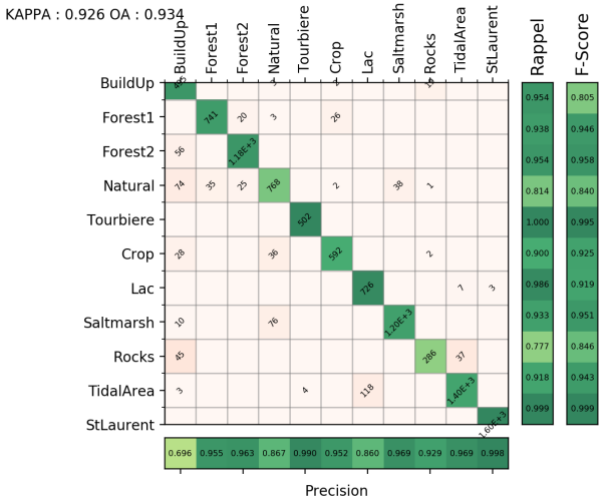

Figure 18. Confusion matrix for the classification using Sentinel 2 earth observation data for the year 2018 (a) and year 2019 (b).

4. Summary

During the frame of the Coastal erosion from space funded by the European Space Agency the project leader (Argans) based on the requirement of the End-Users from 4 countries (UK, R. of Ireland, Spain and Canada) has developed satellite derived products to assess coastal change.

This section details some highlight of the products available:

- The satellite derived waterline (optical) has been available for the 25 years' time series of data (1995 to 2019) showing changes of the shore through time. The presence of quality flags helps to select the best segments for the validation analyses.
- The satellite derived shoreline (optical) shows consistency with in-situ validation data at mean sea level and accuracy below the pixel resolution.
- The satellite derived bathy-morpho-terrain-model in particular clear water shows interesting result to monitor changes on shore proximity and sand bars.
- The habitat maps can be considered as the initial condition for the land coverage monitoring, providing a crucial starting point for a long-term monitoring.

5. References

Didier, D., Bernatchez, P., Augereau, E., Caulet, C., Dumont, D., Bismuth, E., Cormier, L., Floc'h, F., & Delacourt, C. (2017). LiDAR Validation of a Video-Derived Beachface Topography on a Tidal Flat. Remote Sensing, 9(8), 1–22. https://doi.org/10.3390/rs9080826

DREJZA, S., FRIESINGER, S., P. BERNATCHEZ et G. MARIE (2014), Vulnérabilité des infrastructures routières de l'Est du Québec à l'érosion et à la submersion côtière dans un contexte de changements climatiques : Développement d'une approche et d'un indice pour quantifier la vulnérabilité des infrastructures routières à l'érosion et à la submersion côtière dans un contexte de changements climatiques sur 9 sites témoins. Volume III. Projet X008.1. Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. Remis au ministère des Transports du Québec, mars 2015, 308 p.

Dubois, J.-M. M., Bernatchez, P., Bouchard, J.-D., Daigneault, B., Cayer, D., Dugas, S. (2005) Évaluation du risque d'érosion du littoral de la Côte-Nord du Saint-Laurent pour la période de 1996-2003. Pour la Conférence régionale des élus de la Côte-Nord, 291 pages, annexes.

6. Appendix – Annex B

ANNEX B. SERVICE ASSESSMENT SHEET

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

The interest for this product is high as it can be used to create a baseline from which assessing coastal erosion dynamics and changes in waterline/shoreline.

M**inimum cell size: (or mapping unit):** 5m (Sentinel 1) to 10 m (Sentinel 2) resolution

Product accuracy (from Table 34, from the URD): +/-10 m

***L**ow; **M**edium; **H**igh

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

According with the List of EO products with their description (see Table 1.1 of the Products Validation Plan Document (SO-TR-ARG-003-055-009-PVP), SDW EO products associated ate listed below:

Product Name	**Description**
CE_ARG_area_L2_1D_OB_WL_sensor_date.shp	Observed waterline from a single optical snapshot for a specific area and date
S1A_IW_GRDH_1SDV_ *date_date_element*.geojson	Observed waterline from a single Sentinel-1 (SAR) snapshot for specific area and date

At the date of this evaluation (14/01/2021) the end-user has received, via ftp, the following number of products:

Product Name	**Quantity**
CE_ARG_area_L2_1D_OB_WL_sensor_date.shp	: 569(from 1995 to 2020)
S1A_IW_GRDH_1SDV_ *date_date_element*.geojson	: 779 (from 2015 to 2019)

Compliance with general product description is **MEDIUM**. New quality flags have been applied in the metadata, it captures properly the confidence in the position of the waterline. Moreover, waterlines (OPT and SAR) cover two different sectors. SAR waterline data are missing the quality flags and seem to have numerous position problems.

***L**ow; **M**edium; **H**igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
	x		x

Comments:

The accuracy compliance of the OPT waterlines is considered **HIGH** for the following reasons:

- The SAR SDW in some areas seems to be too smoothed. However, no relevant interruptions were present.
- The OPT SDW also presents some gaps over small areas probably due to sandbanks (Figure 4).
- The large number of WL data for the different AOI allows users to see the retreat of the beach and the movement of sand bars. (Figure 6).
- Quality flags have largely improved the uses of the waterline delineation. (Figure 5)

The accuracy compliance of the SAR waterlines product is considered **LOW**.

***L**ow; **M**edium; **H**igh

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
	x		**X**

Comments:

The confidence in the quality of the OPT waterlines product is considered **HIGH** for the following reasons:

- New processing includes essential quality flags from the waterline position.
- A large number of data is an asset to assess the spatial variability of the waterline.
- Waterline generated by optical data would be quantitatively validated with in-situ data provided by UQAR

The confidence in the quality of the SAR waterlines product is considered **LOW**.

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
	x		**X**

Comments:

Waterline can provide information about the geomorphological process on the shore (sediments accretion and erosion). The confidence in the product quality is considered **HIGH** for the OPT waterline**. SAR** waterline still needs to be improved (QC, flagging) to be of interest.

***L**ow; **M**edium; **H**igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
		X	

Comments:

The impact of the service and product on the current end-user practices is considered **MEDIUM**. There is of interest for research purposes and new waterline time series has been considered by UQAR to perform research in the Canadian Arctic to assess first nations coastal vulnerability.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:

See the comment above, for research purposes, this product would probably be used to monitor the coastal evolution of the last decade. Application in coastal management could consider this product to assess the impact on the shore ecosystems (dunes and vegetation).

***L**ow; **M**edium; **H**igh

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

SAR waterline could not be used in synergy with the OPT waterline, for the moment too many discrepancies between both lines do not allow the use of SAR data. Improvement needs to be considered for the SAR waterline.

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
			X

Comments:

As mentioned above, product demonstration in the Arctic is considered by the academic partner. With extensive erosion of the Canadian shoreline, the need for operational and continuous monitoring of the shoreline (waterline) should be considered to assess the temporal and spatial changes. This evaluation is considered HIGH.

***L**ow; **M**edium; **H**igh

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The overall service and products are considered **MEDIUM** for the following reasons:

- The use of the long archives of optical data from L5 to S2
- Possibility of monitoring of instantaneous waterline changes over 20 years of data

***L**ow; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			x

Comments:

Recommendation:

- Maintain a nationwide web portal and data dissemination with a recurrent update on the products

***L**ow; **M**edium; **H**igh

End-User : ARCTUS Inc
Contact : Christiane Dufresne & Thomas Jaegler
Version : 12/02/2021
Filename : ARCTUS_ANNEXB_SOW_Shoreline_delineation

ANNEX B. SERVICE ASSESSMENT SHEET

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

The interest for this product is high as it can be used to create a baseline from which assessing coastal erosion dynamics and changes in waterline/shoreline.

Minimum cell size: (or mapping unit): 5m (Sentinel 1) to 10 m (Sentinel 2) resolution

Product accuracy (from Table 34, from the URD): +/-10 m

***Low**; **M**edium; **H**igh

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:
According with the List of EO products with their description (see Table 1.1 of the Products Validation Plan Document (SO-TR-ARG-003-055-009-PVP), SDS EO products associated ate listed below:

Product Name	**Description**
CE_date_SL_DB_l2_area_HHW_sensor_date.shp	Observed shoreline for the High High-Water datum at for a specific area and date
CE_date_SL_DB_l2_area_HHWS_sensor_date.shp	Observed shoreline for the High High-Water Spring datum at for a specific area and date
CE_date_SL_DB_l2_area_MSL_sensor_date.shp	Observed shoreline for the Mean Sea Level datum at for a specific area and date
CE_date_SL_DB_l2_area_LLW_sensor_date.shp	Observed shoreline for the Low-level Water datum at for a specific area and date
CE_date_SL_DB_l2_area_LLWS_sensor_date.shp	Observed shoreline for the Low-Level Water Spring datum at for a specific area and date
CE_date_SL_DB_l2_area_HHW_S1_date.shp	Observed shoreline for Sentinel-1 (SAR) for the High High-Water datum for specific area and date
CE_date_SL_DB_l2_area_HHWS_S1_date.shp	Observed shoreline for Sentinel-1 (SAR) for the High High-Water Spring datum for specific area and date
CE_date_SL_DB_l2_area_MSL_S1_date.shp	Observed shoreline for Sentinel-1 (SAR) for the Mean Sea Level datum for specific area and date
CE_date_SL_DB_l2_area_LLW_S1_date.shp	Observed shoreline for Sentinel-1 (SAR) for the Low-Level Water datum for specific area and date
CE_date_SL_DB_l2_area_LLWS_S1_date.shp	Observed shoreline for Sentinel-1 (SAR) for the Low-Level Water Spring datum for specific area and date

At the date of this evaluation (12/02/2021) the end-user has received, via ftp, the following number of products:

Product Name	**Quantity**
CE_date_SL_DB_l2_area_datum_sensor_date	: 591(from 1995 to 2020)
S1A_IW_GRDH_1SDV_ *date_date_element*.geojson	: 139(from 2015 to 2019)

Compliance with general product description is **MEDIUM**. Quality flags have not been applied in the metadata, we can not capture properly the confidence in the position of the waterline. SAR waterline data are missing the quality flags and seem to have numerous position problems.

***Low**; **M**edium; **H**igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
	x	x	

Comments:

The accuracy compliance of the OPT shoreline is considered **MEDIUM** for the following reasons:

- The need for auxiliary data (waves, wind, tides, and beach slope) is limited at a certain area of interest. Therefore, the shoreline covers less ground than the Waterline.
-

The accuracy compliance of the SAR shoreline is considered **LOW** for the following reasons:

- has not been as good as the optical shoreline, the line where smoothing and doesn't capture well the shore position.

*Low; **M**edium; **H**igh

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
	x	x	

Comments:

The confidence in the quality of the OPT shoreline product is considered **MEDIUM** for the following reasons:

- New processing does not include essential quality flags from the shoreline position.
- A large number of data is an asset to assess the spatial variability of the Shoreline.
- Shoreline generated by optical data would be quantitatively validated with in-situ data provided by UQAR

The confidence in the quality of the SAR shoreline product is considered **LOW**.

*Low; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
	x	x	

Comments:

The confidence in the product quality is considered **MEDIUM** for the OPT shoreline for the following reasons:

- Shorelines are strongly linked to the waterline and the "shape" of the coast (sandy, cliff). On sandy shore with large flats, results are better than on cliffs.

The confidence in the product quality is considered **LoW** for the **SAR** shoreline still needs to be improved to be of interest.

***L**ow; **M**edium; **H**igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
		X	

Comments:

The impact of the service and product on the current end-user practices is considered MEDIUM for the following reasons:

- Availability of a long time series (2002 to 2019) of OPT shorelines could be used to assess the shore retreat of accretion as shown in the validation section: Shoreline timeseries
- SAR shoreline could not be evaluated in the frame of the projects.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The probability of service integration into existing practices is considered as **MEDIUM** for the following reasons:

- for research purposes, this product would probably be used to monitor the coastal evolution of the last decade.
- The trend can be calculated to assess the erosion or accretion process (see section: Shoreline timeseries of the validation documents).
-

***L**ow; **M**edium; **H**igh

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Desired service and/or product(s) improvements are considered as **MEDIUM** for the following reasons:

- SAR waterline could not be used in synergy with the OPT waterline, for the moment too many discrepancies between both lines do not allow the use of SAR data.
- Improvement needs to be considered for the SAR waterline.
- Adding quality control flags to the shoreline as for waterline would be an important improvement for the shoreline delineation
-

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
			X

Comments:

The needs for a large-scale service/product demonstration are considered as **HIGH** for the following reasons:

- Demonstration in the Arctic is considered by the academic partner. With extensive erosion of the Canadian shoreline, the need for operational and continuous monitoring of the shoreline should be considered to assess the temporal and spatial changes.

***L**ow; **M**edium; **H**igh

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The overall service and products are considered **MEDIUM** for the following reasons:

- **SAR** shoreline has not been delivered in time to be validated/evaluated
- **OPT** shoreline is considered enough accurate to assess the trend of the shoreline displacement.

*Low; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			x

Comments:

Recommendation:

1. Maintain the improvement of the SAR shoreline to get the benefice of the radar technology.
2. Apply the processor to third party missions such as the Canadian Radarsat Constellation Mission.
3. Apply shoreline processor to VHR data (< 5 m) to have a finer resolution of the shoreline migration

*Low; **M**edium; **H**igh

End-User : ARCTUS Inc.
Contact : Christiane Dufresne & Thomas Jaegler
Version : 12/02/2021
Filename : ARCTUS_ANNEXB_SOW_TopoBathymetry

ANNEX B. SERVICE ASSESSMENT SHEET

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

The interest for this product is high since a large part of the population and infrastructure are localized along coastal areas. The synoptic view of the remote sensing data can be used by the Government of Quebec to assess the near-shore bathymetry change, and the dynamics of the bathy-morphology due to coastal erosion. The accuracy definition and aspirational values for this product is shown below.

Product accuracy (copied from Table 30, from the URD):
+/-15cm vertical RMSE (to allow comparison with LiDAR data).

***L**ow; **M**edium; **H**igh

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

According with the List of EO products with their description (see Table 1.1 of the Products Validation Plan Document (SO-TR-ARG-003-055-009-PVP), SDBTM EO products associated are listed below:

Product Name	**Description**
CE_ARG_area_L2_3D_BT_SDB_sensor_date.tif	: Bathymetry chart from a single optic EO product (**classic SDB**)
CE_ARG_area_L3_3D_BT_SDB_sensor_date_date.tif	: Time-series & merged chart from several SDB / optic EO products
CE_SAT_area_L2_3D_BT_WF_sensor_date.XXX	: Seafloor morphology and depth from a wave field analysis from a single SAR snapshots
CE_SAT_area_L3_3D_BT_WF_sensor_date_date.XXX	: Time series of seafloor morphology and depth from a wave field analysis of SAR snapshots
CE_ARG_area_L2_3D_BT_WF_sensor_date.XXX	: Seafloor morphology, incl. depth & slope from a wave field analysis of a single optical EO snapshot
CE_ARG_area_L3_3D_BT_WF_sensor_date_date.XXX	: Time series of seafloor morphology, incl. depth & slope from a wave field analysis of optical EO snapshots
CE_ARG_area_L4_3D_BT_SDB_WF_sensors_date_date.tif	: Seafloor morphology and depth from a fusion between SDB chart and wave field analysis from a time series

At the date of this evaluation (14/01/2021) the end-user has received, via ftp, the following number of products:

Product Name	**Quantity**
CE_ARG_area_L2_3D_BT_SDB_sensor_date.tif	: 21 images (dates: 2016-2019 and 2017-2019)
CE_ARG_area_L3_3D_BT_SDB_sensor_date_date.tif	: 0
CE_SAT_area_L2_3D_BT_WF_sensor_date.XXX	: 0
CE_SAT_area_L3_3D_BT_WF_sensor_date_date.XXX	: 0
CE_ARG_area_L2_3D_BT_WF_sensor_date.XXX	: 0
CE_ARG_area_L3_3D_BT_WF_sensor_date_date.XXX	: 0
CE_ARG_area_L4_3D_BT_SDB_WF_sensors_date_date.tif	: 0

Compliance with general product description is **MEDIUM**. The .tif file L2_3D_BT_SDB product received contains only 5 bands with different elevation metrics (Band 1: Z_mean; Band 2: Z_median; Band 3: Z_90pct_min; Band 4: Z_90pct_max; Band 5: Z_90pct_range) but no other kind of information or metadata are included (e.g. datum).

***L**ow; **M**edium; **H**igh

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The accuracy compliance of the L2_3D_BT_SDB raster is considered **MEDIUM** for the following reasons:

- Some gaps are present over small areas probably due to waves foam, so it is not a real issue.
- Some pixels show redundant constant values due to the atmospheric correction processing (Fig.11).

- Data provided for Pointe aux Outardes AOI shows several constant pixels for around -2m and -4m these are due to the high absorbing sediment and color dissolved organic matter and should be masked to do a proper validation.
- Differences between several years are the best tool to observe changes on sand banks and shoals.
- Some unrealistic changes between bathymetric bands are present in some areas. The most evident was close the mouth of the Mingan river (i.e. the bathymetry was higher than 15 meter – see Figure 8) and in some zones very close to the beach (Figure 8). No reprocessed data since April 2020 has been generated for the Mingan area of interest.

- Data for the Magdalen Island shows realistic changes on the nearshore sand bars (Figure 9). Analyses would be done for this area of interest (see section: BATHYMETRY).

***L**ow; **M**edium; **H**igh

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The confidence in the quality of the L2_3D_BT_SDB product is considered MEDIUM for the following reasons:

- For certain AOI, there is a lack of accuracy due to the water colour properties.
- Considering that the lack of training data and the complexity of the Canadian water, good performance in the Pointe-aux-Loups area is a good achievement.

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The confidence of the product quality and accuracy can be considered **MEDIUM** for the following reason:

- Numerous pixels has constant values
- The mask product based on the water column quality is a first step to understand the quality and discrepancies of the Satelite derived bathy-morpho-terrain-model (SDBMTM)
- Still, improvements need to be made to have a better and consistent product.

***L**ow; **M**edium; **H**igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Impact of the service and products on current end-user practices is considered **MEDIUM** for the following reasons:

- The changes between SD-BM-TM when the atmospheric correction parameter changes lead to major changes in uncertainty.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
	x		

Comments:

Assessing bathymetry changes on the shallow nearshore regions is important for the safety and coastal changes monitoring. Product is for the moment not as expected by the end-users to be integrated into the existing practices. The probability of integration to existing practices is considered as **LOW.**

***L**ow; **M**edium; **H**igh

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Running the contractor's algorithms on Mingan AOI would be the last improvement of the 2 existing bathy-morphology.

- Good comprehension of the processing and the physics of the bathymetric estimation
- Still, room for improvement in the St-Lawrence water due to a complex mixture of suspended sediment and colour dissolved organic matter.

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
		x	

Comments:

It will be interesting to test the product in different coastal areas of Quebec when the overall accuracy of the product will be improved.

***L**ow; **M**edium; **H**igh

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The overall service and products are considered **MEDIUM** for the following reasons:

- The processor of the SDB product still need improvement for the particularity of the atmospheric parameters

***L**ow; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
			x

Comments:

Recommendation for ESA is **HIGH:**

- Improve the knowledge of the atmospheric parameters for better atmospheric correction.

***L**ow; **M**edium; **H**igh

End-User : ARCTUS Inc
Contact : Christiane Dufresne & Thomas Jaegler
Version : 12/02/2021
Filename : ARCTUS_ANNEXB_SOW_Habitat_Maps

ANNEX B. SERVICE ASSESSMENT SHEET

The following Service Assessment Sheets shall be separately completed by each end-user and by the Contractor, at the Mid Term Review and at the Final Review.

B.1 Assessment of the user requirements

Adequacy of the User Requirements Document (URD) requirements (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

The interest for this product is high as it can be used to assess the backshore land use-land cover changes due to coastal erosion. The last land cover and habitat maps published covered the period between 1999 to 2005.
The information about Habitat maps will be useful to assess the changes or loss of usable land on the backshore environment.
High priority should be to assess the change on

(1) Beach
(2) Ice ridge
(3) Dense artificial surface and associated areas,
(4) Diffuse artificial surface and associated areas,
(5) Road
(6) Cultivated and Managed Terrestrial Areas

Lower priority :

(7) Forest
(8) Water bodies

M**inimum cell size: (or mapping unit):** 10 m (Sentinel 2) resolution

Product accuracy (from Table 35, from the URD): +/-10 m

***L**ow; **M**edium; **H**igh

B.2 Product compliance

Overall product compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The Habitat map produced for the 2 study case are considered adequate with **MEDIUM** score for the following reasons:

According to the **List of EO products with their description** (shown in Table 1.1, page 11 of the Products Validation Plan Document [ref: SO-TR-ARG-003-055-009-PVP] version 13/01/2020), EO products associated to HABITAT MAPS are:

Product Name	**Description**
CE_ARG_area_L2_2D_FB_LULC_sensor_date.shp	: LULC map from a single EO product
CE_ARG_area_L3_2D_FB_LULC_sensor_date_date.tif	: LULC map from a time series of EO optical products

At the date of this evaluation (28/01/2020) the end-user have received, via ftp, the following amount of products:

Product Name	**Quantity**
CE_ARG_area_L2_2D_FB_LULC_sensor_date.shp	: 0
CE_ARG_area_L3_2D_FB_LULC_sensor_date_date.tif	: 3

*File name provided "CE_date_LC_FB_L3_area_sensor_date_date.tif" differ from expected

***L**ow; **M**edium; **H**igh

End-User : ARCTUS Inc
Contact : Christiane Dufresne & Thomas Jaegler
Version : 12/02/2021
Filename : ARCTUS_ANNEXB_SOW_Habitat_Maps

Product accuracy compliance to the user requirements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The accuracy compliance of the habitat maps is considered MEDIUM for the following reasons:

- The available dataset is limited to 2 regions of interest and 2 years for the Manicouagan area and 1 year for the Magdalen Island area. (Figure 17)
- Classes are well chosen but some of the features from the land use (peat bog exploitation) are not well capture.
- Local expertise still needed for the definition of the classes and the validation of the polygon.
- Changes between years can be quantified by calculating the surfaces by classes.

*Low; Medium; High

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
			x

Comments:

The confidence in the product quality of the habitat maps is considered **HIGH** for the following reasons:

- The confidence matrix and kappa coefficient show excellent results with a value above 0.90

***L**ow; **M**edium; **H**igh

B.3 Utility assessment

Confidence in the product quality (including accuracy)	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The confidence in the product quality is considered as **MEDIUM** for the following reasons:

- Metadata and confusion matrix shows good accuracy of the classification
- The processor used was train for each year to reproduce the method for different years the need is to reuse the existing model.

***L**ow; **M**edium; **H**igh

Impact of the service and products on current end-user practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The integration of the service and products on current end-user practices is considered as **MEDIUM** for the following reasons:

- End-users could possibly integrate this new product in their further research.

***L**ow; **M**edium; **H**igh

B.4 Future outlook

Probability of service integration into existing practices	Evaluation*		
	L	**M**	**H**
		x	

Comments:
The probability of service integration into existing practices is considered as **MEDIUM** for the following reasons:

- End-user is not currently using habitat mapping as a current product for the monitoring of coastal changes.
- Improvement of the long-term changes of habitat could emphasize the potential

***L**ow; **M**edium; **H**igh

Desired service and/or product(s) improvements	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Desired service and/or product(s) improvements are considered as **MEDIUM** for the following reasons:

- Improvement of the method to apply classification to the long-term archive of Landsat 5 and Landsat 8 need to be done

***L**ow; **M**edium; **H**igh

Needs for a large-scale service/product demonstration	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Needs for a large-scale service/product demonstration is considered as **MEDIUM** for the following reasons:

- Habitat mapping in other areas of interest in Canada could be a need, particularly in the Arctic where the loss of land due to permafrost taws.

***L**ow; **M**edium; **H**igh

B.5 Overall evaluation

Overall service and products evaluation	Evaluation*		
	L	**M**	**H**
		x	

Comments:

The overall service and products are considered **MEDIUM** for the following reasons:

- The use of the long archives of optical data from L5 to S2.
- Possibility of monitoring changes over 20 years of data.
- Data portal is effective for dissemination.

*Low; **M**edium; **H**igh

Recommendations to the European Space Agency Comments:	Evaluation*		
	L	**M**	**H**
		x	

Comments:

Recommendation to the ESA for the habitat map is **MEDIUM** for the following reason:

- Develop a new processor for the habitat map using Landsat5, Landsat8 and Sentinel2 mission.

*Low; **M**edium; **H**igh