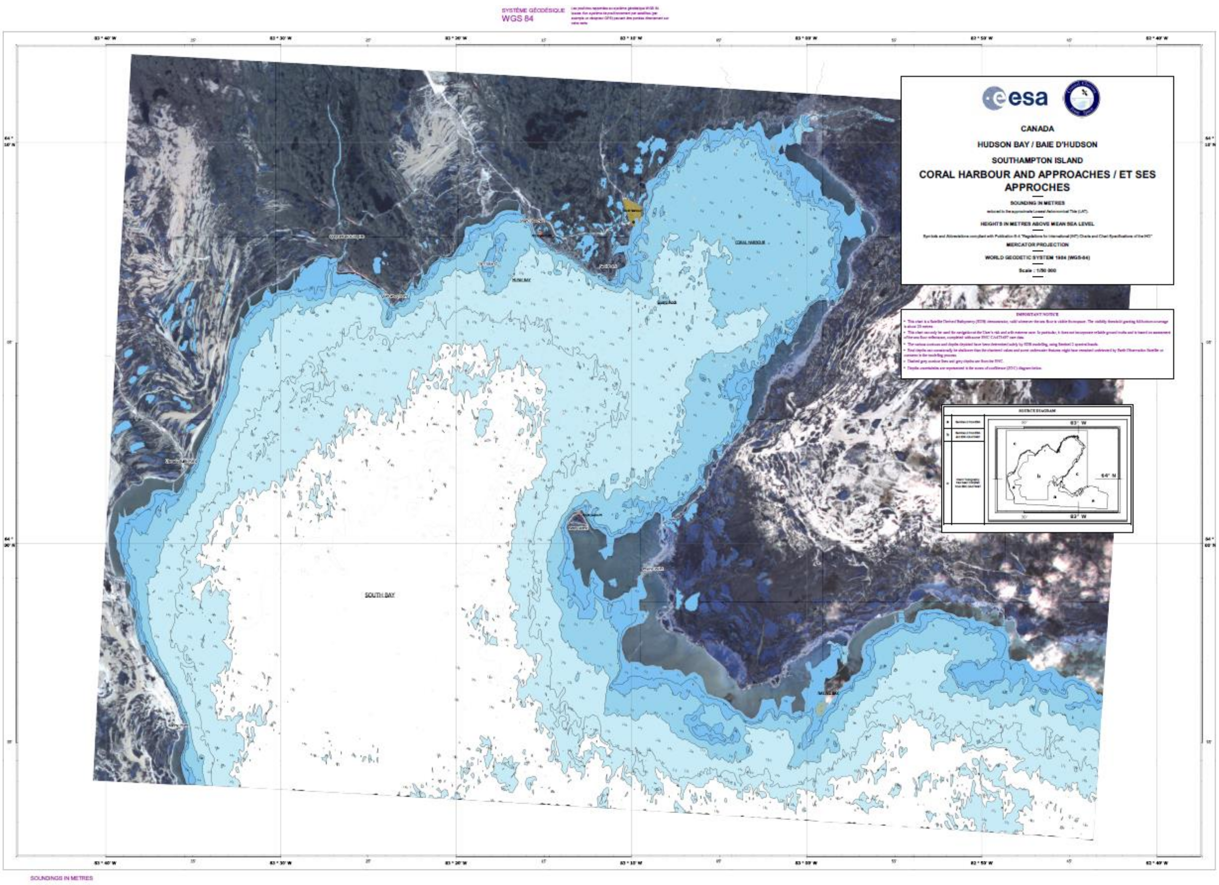
ANNEX D

Coral Harbour



Coral Harbour 1st draft demonstrator

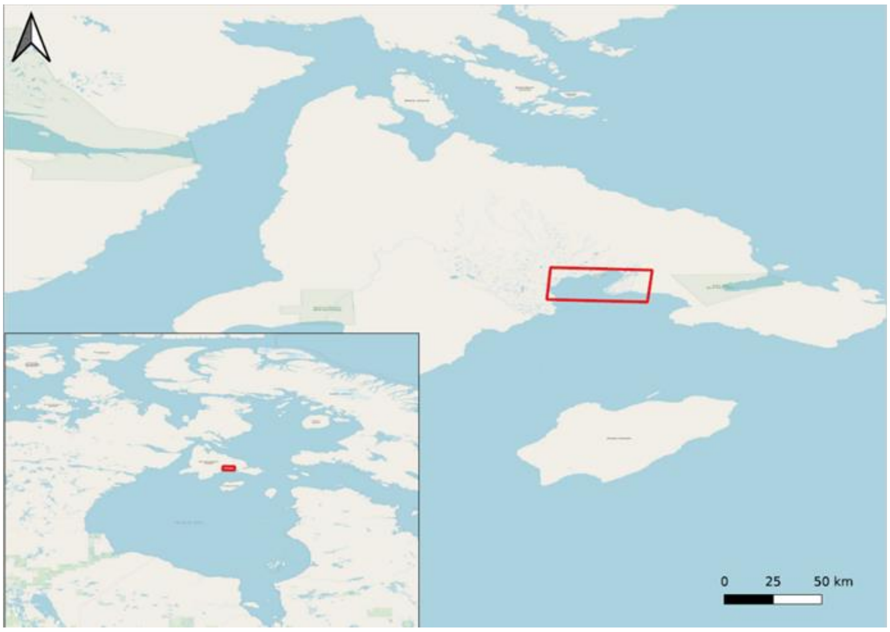
TABLE OF CONTENTS

1. Background Information

1.1 Overview

Located on Southampton Island, Kivalliq Region, in the Canadian territory of Nunavut, Coral Harbour hosts a small Inuit community. This site is a new research field for ARGANS as it provides the first experience of artic water, with possible applications to the North East Passage whilst SDB methods are usually employed in tropical waters. Thanks to the recent Canadian surveys, the region is well documented and should provide ample references to test the Sentinel-2 performances applied to a "Perfect Image" processed with the ***"Merge"*** methodology.

The following figure shows the location of the study site.



Location of Coral Harbour study site. The red outline is the ROI used for SDB.

1.2 Methodology

As Coral Harbour is the first test site ARGANS has produced SDB for within arctic waters it was new research into how SDB can be used within these regions. The initial results for this location were drastically different to what was expected. This was due to changes in the amount of sun energy available and therefore a difference in endmembers being observed. A study was then carried out by extracting information from within the Sentinel-2 images to produce a unique endmember for each land type observed within Coral Harbour. Of course, this does not take into account the water column as these land types were taken from the shoreline. However, using these new endmembers produced high accuracy result when compared to charts.

For Coral Harbour 21 Sentinel-2 L1C images were downloaded and normalised; 19 SDB models were eventually produced and processed with the ***"Merge"*** method. These images and models followed the same inspection as the other test sites and were always compared as the process was carried out to ensure that only the best images were used within the investigation.

1.3 Main results

After changing the endmembers to reflect the Coral Harbour environment, the SDB results provided much better outputs. The bathymetry was checked at every stage again to ensure that only the best models and images were being used within the process. Again, all five "***Merge"*** supervised averaging methods were compared and processed to find the best output. For Coral Harbour two methods produced accurate results although both in slightly different regions of the image. The 'minimum distance' and the uncertainties 'range intersection' (re Final Report, paragraph I.2.4) were both utilised to yield the final SDM models.

1.4 References

Inputs and references are listed at the appendix 2 for clarity. They include the following:

- References of :
  - SDB models :
  - List of used Sentinel-2 images
- References of existing official charts

1.4.1 Project Data files

The Project data files are listed at the appendix 2 , e.g. ""ESA_CH_S2_Auto_IDA_Opt4_v0.tif" and "ESA_CH_S2_Auto_IDA_Opt5_v0.tif"

1.4.2 SDB references

The two DTMs produced for Coral Harbour were obtained by merging 19 individual models and applying the following supervised averging methods:

- "ESA_CH_S2_Auto_IDA_Opt4_v0.tif" [Merged model using option 4 (distance weighted average method)]
- "ESA_CH_S2_Auto_IDA_Opt5_v0.tif" [Merged model using option 5 (range intersection method)]

The Option 4 model produces better results in shallow waters and Option 5 better results in deeper areas.

Sentinel-2 images used by this demonstrator are listed in appendix 2.

1.4.3 Existing official charts' and ENCs' references

- Chart: N° 2019RM-5410-V3 (1: 50 000) [Coral Harbour and Approaches/*et les approches* (Last update 2019-07-16)] [depths in fathoms] - Canada
- ENC: the only ENC is: CA473497 – 1: 25 000- Approach – Canada

1.4.4 Existing surveys

The Canadian Hydrographic Service owns its raw survey data and accepts to give access to these pending an agreement which has been requested and accepted in principle, but the data have not been released yet.

Although it is intended to use these raw data later, it has been considered interesting to produce SDB bathymetric layers deprived of any previous information as it would give a good idea of the challenges Mariners would have to face when sailing in the North West Passage's unsurveyed waters with only satellite nautical charts.

2. Hydro-Cartographic Qualification of Demonstrator

2.1. Objectives (WP: 2, 6, 8, 9, 10)

⇨ Provide internal feedback to the SDB Analysts and

⇨ after replay, produce a final DTM and the associated ZOC information required to complete the Proposal's Work Packages.

⇨ As Option 5, produce a well-defined 20 metre contour and a reasonable 10 metre contour without spending too much time in very shallow water, especially close to land, known to be problematic. it has been decided to split the area as follows:

a. ESA_CH_S2_Auto_IDA_Opt4_v0.tif : 0 – 5m

b. ESA_CH_S2_Auto_IDA_Opt5_v0.tif : > 5m

⇨ The coastal dispersion by depths less than 5 metres is indeed an old problem which might be caused by the existence of several solutions to the RTE (re Final Report, paragraph III-1.3.3), in which case a ***"Merge"*** solution can only yield bad results. We are actually thinking of combining a ***"Merge"*** profile obtained by averaging time series when appropriate and a unique profile in the first 5 metres to avoid having to average non-gaussian solutions. The difficulty, which can be solved by cartographers' software, is to avoid creating an artificial dogleg when the two profiles join.

2.2. Cartographic Qualification by comparison against ENCs

The figures bellow show how Sentinel-2 images may improve the existing charts.

2.2.1. Coastline

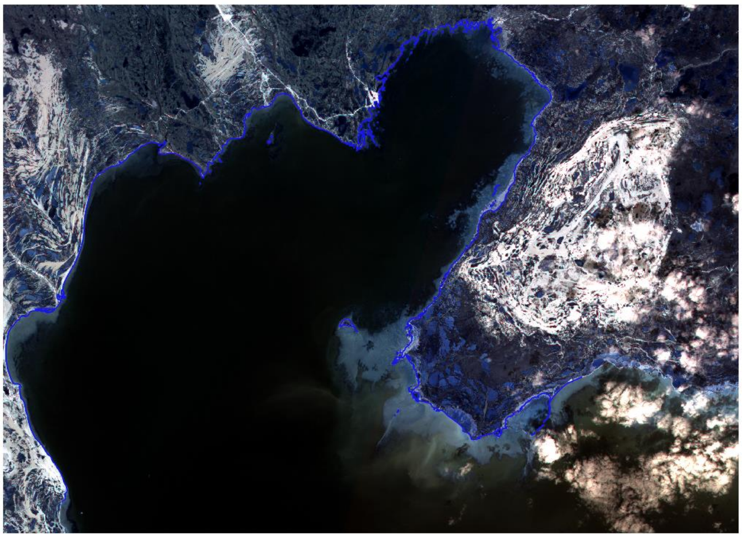
References:

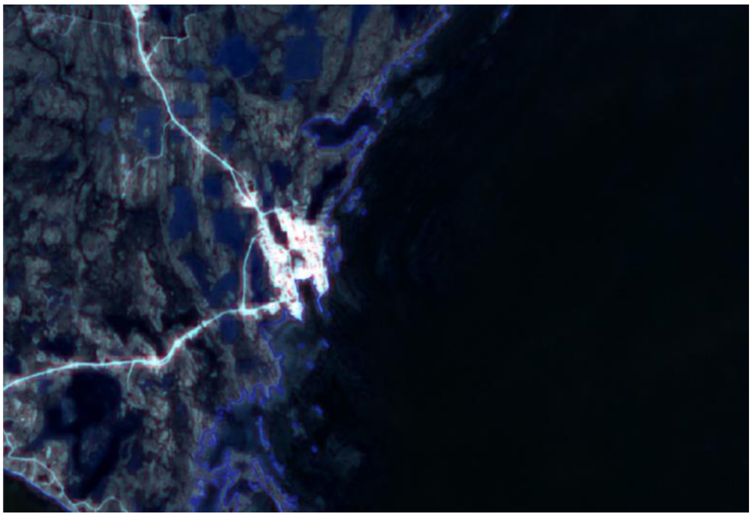
- Sentinel 2 image : S2_20180726_T6WFS
- ENC: CA473497 COALNE

Findings:

The blue ENC coastline matches well the Sentinel 2 coastline.

This means that cartographers can rely on Sentinel 2 images to draw the coastline on charts, thanks to the Sentinel-2 absolute 12-metre WGS 84 horizontal precision.





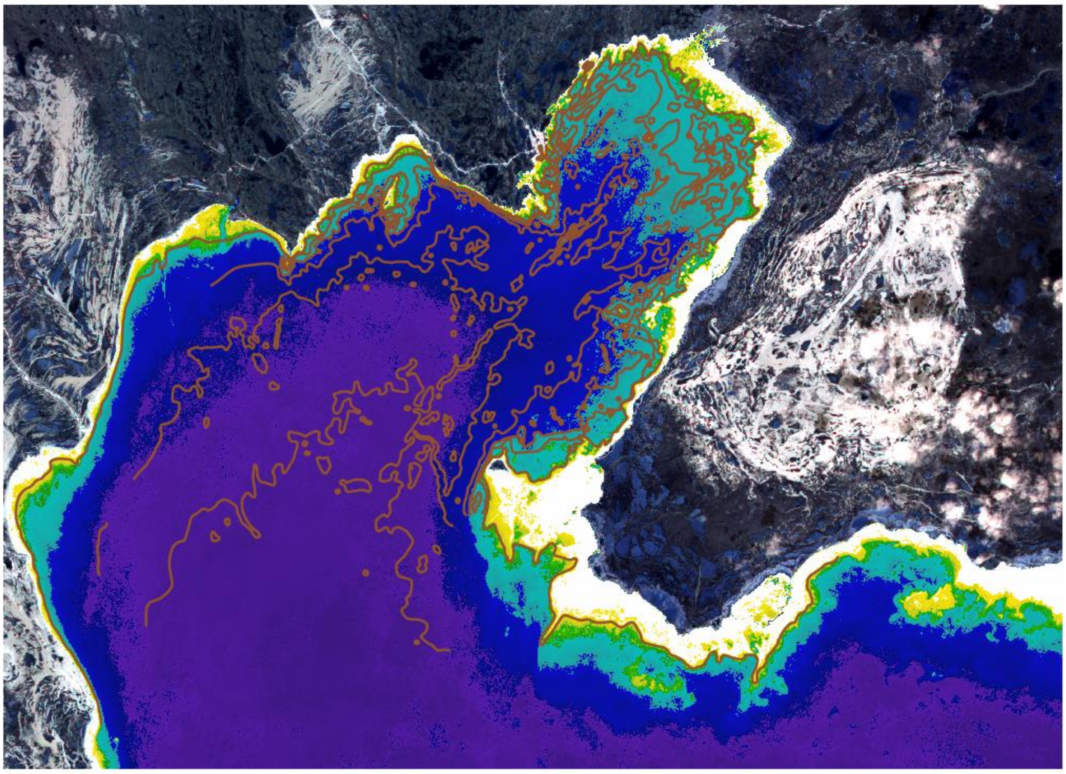
2.2.2. Depth contours

References:

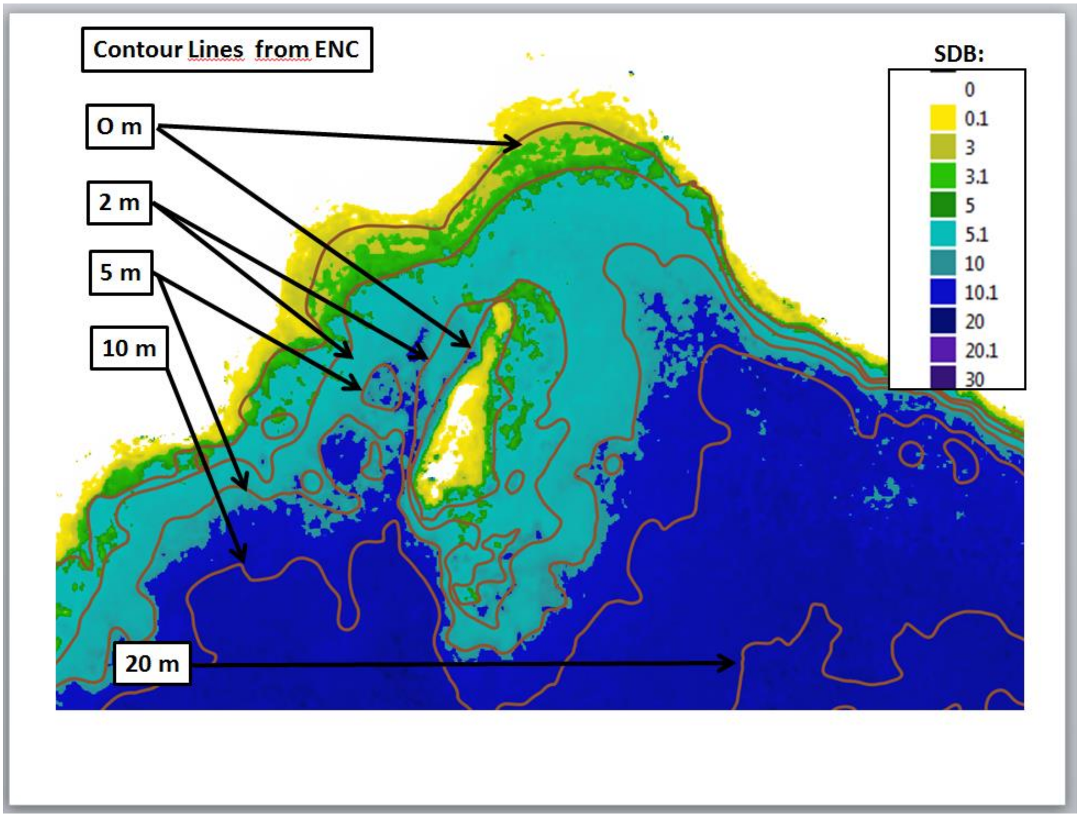
- Sentinel-2 image : S2_20180726_T6WFS
- SDB : ESA_CH_S2_Auto_IDA_Opt5_v0
- ENC: CA473497 DEPCNT

Findings:

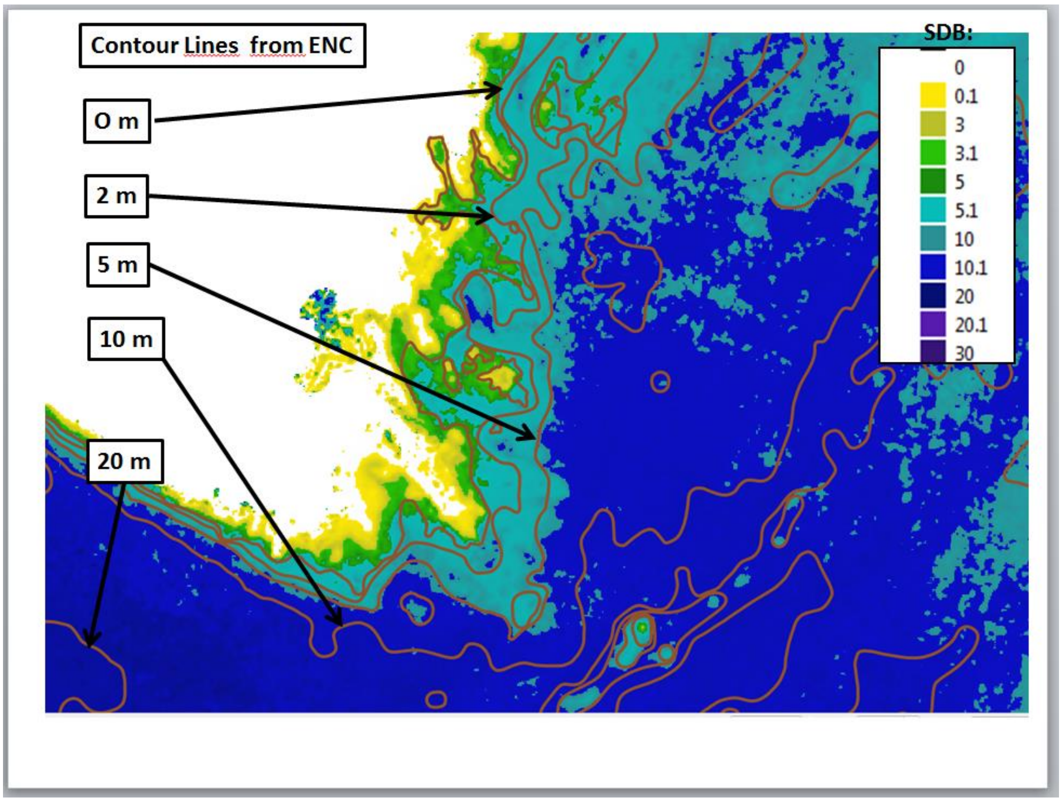
- SDB represents well the different depth categories;
- It is nevertheless difficult to check the fine accuracy of the values of the SDB's depths since ENC depth contours are drawn to reduce the risks of groundings. As a principle, charted contours are always depicted at such a position that true depths are in fact deeper than shown on the chart.
- To be more accurate the comparison should be done not with charts or ENCs (drawn with the Safety of Navigation in mind) but with the original survey data not usually released to the public as "open source".

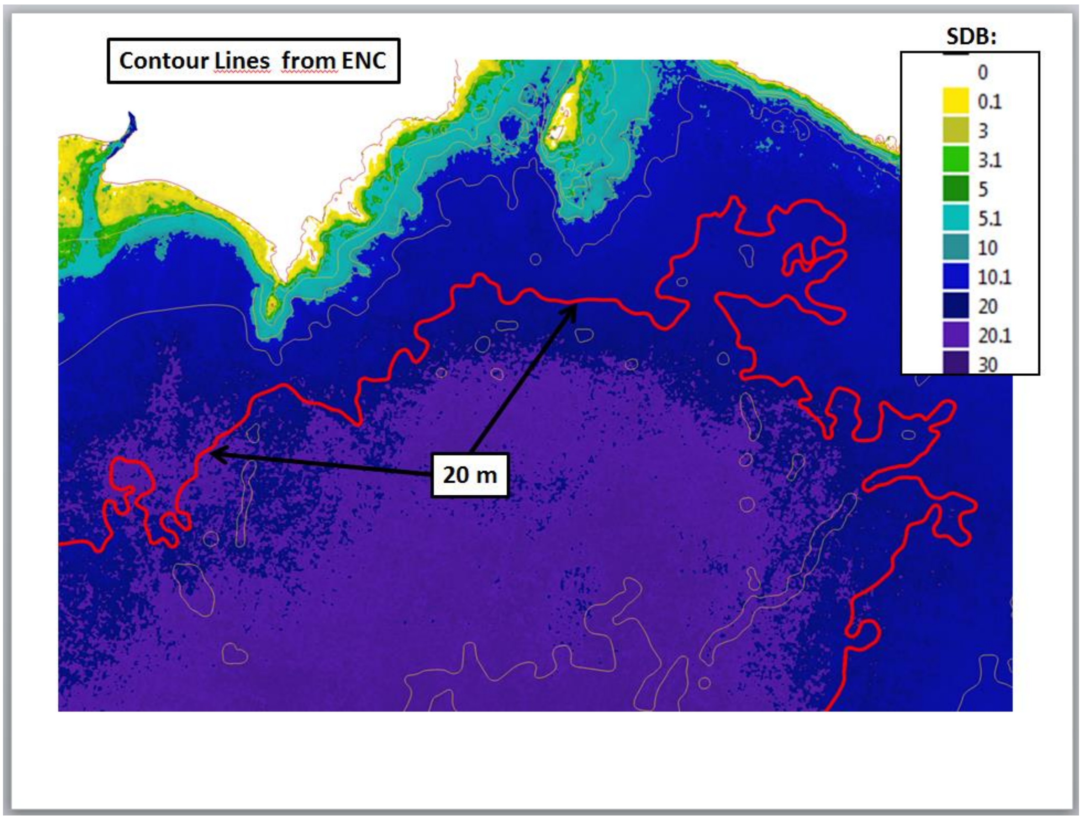


Whole area

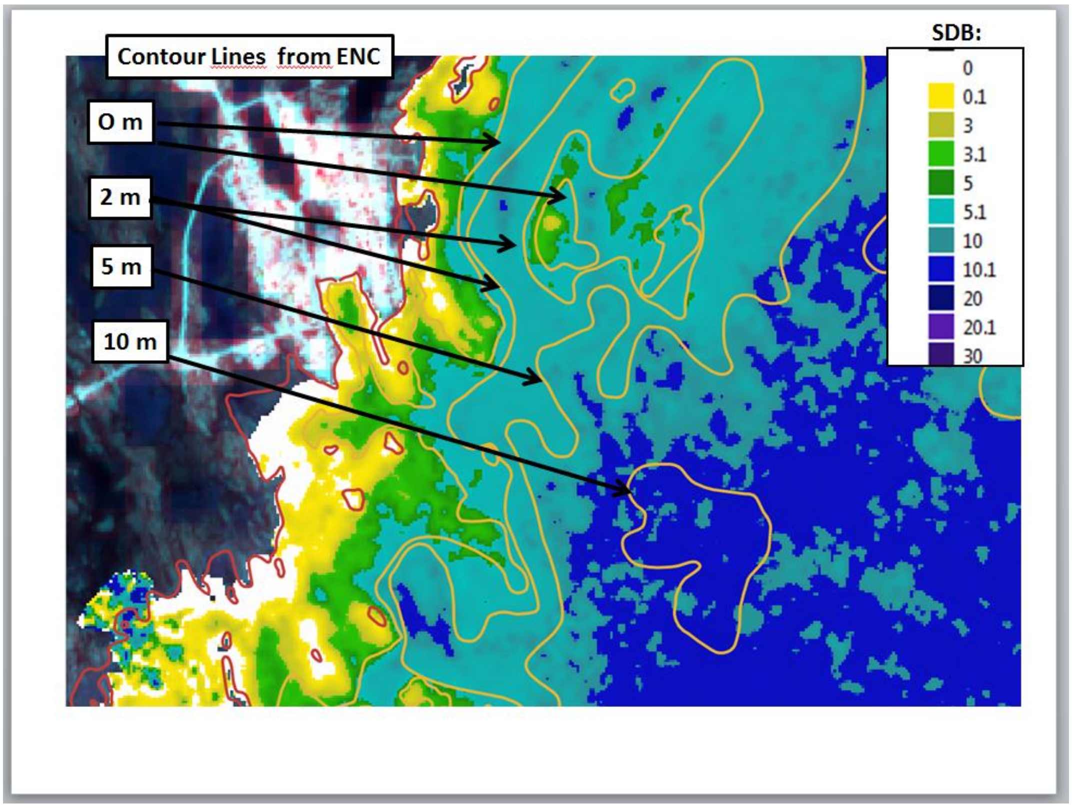

Contour Lines from ENC
0 m
2 m
5 m
10 m
20 m
SDB:
0
0.1
3
3.1
5
5.1
10
10.1
20
20.1
30

Munn Bay


Contour Lines from ENC
0 m
2 m
5 m
10 m
20 m
SDB:
0
0.1
3
3.1
5
5.1
10
10.1
20
20.1
30



20 m Depth contours



Depths in the vicinity of Coral Harbour

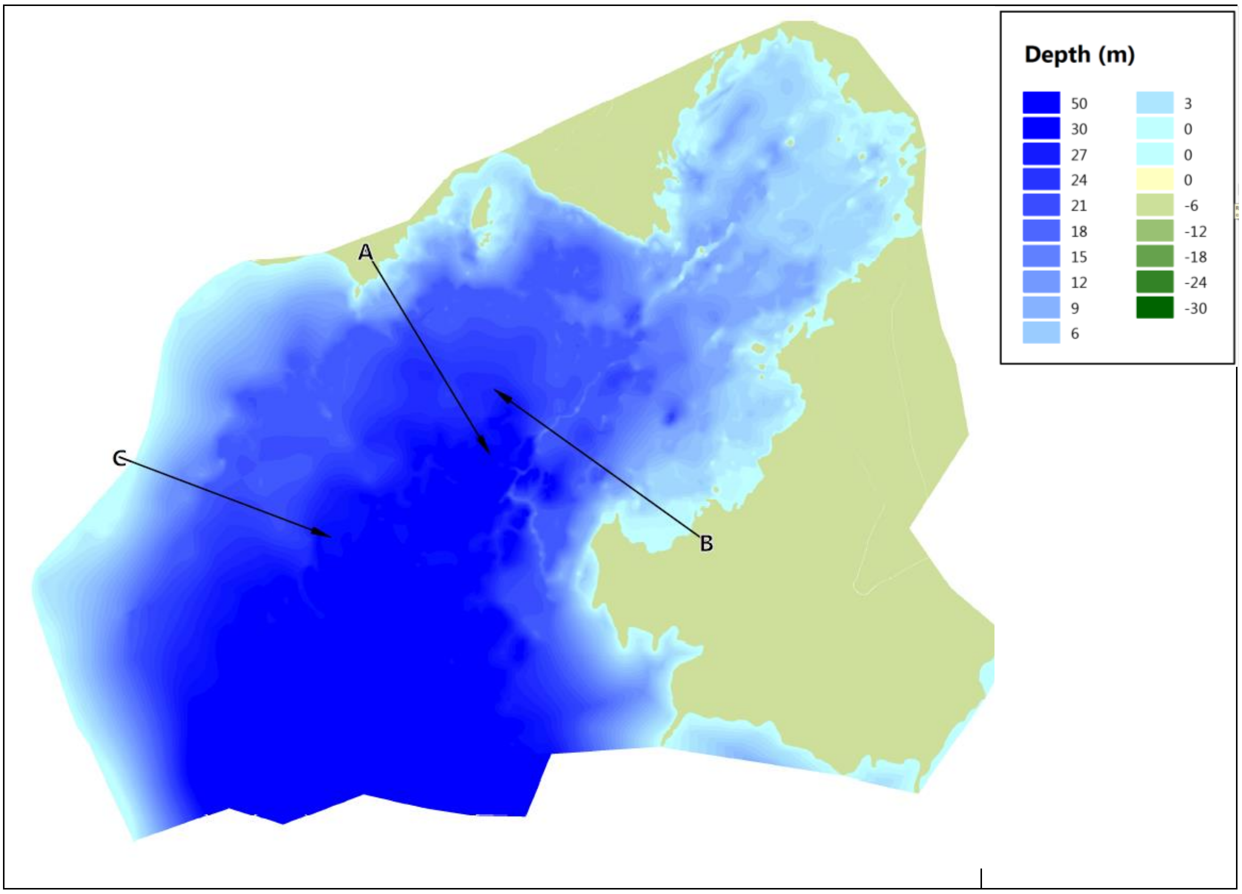
2.2.3. Cross sections

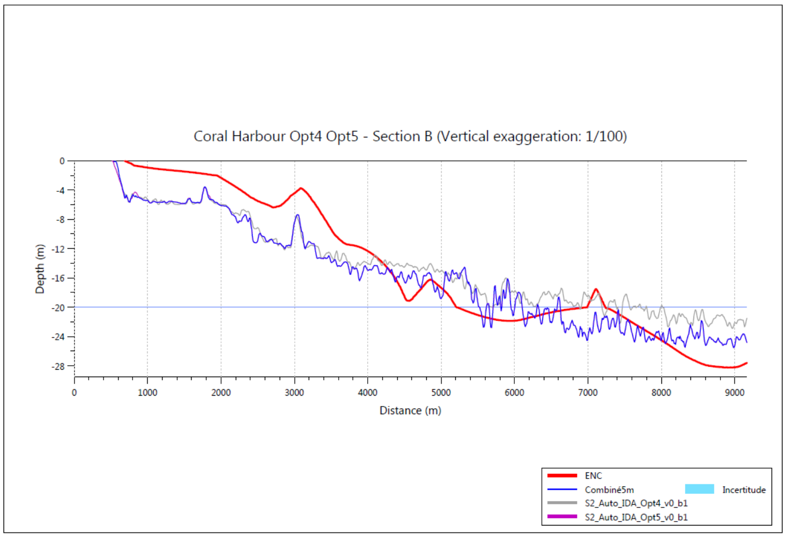
References:

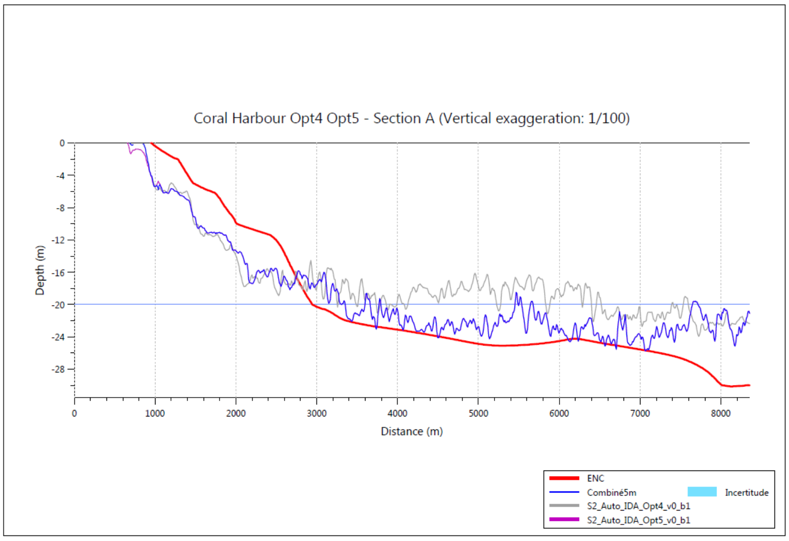
- SDB :
  - ESA_CH_S2_Auto_IDA_Opt4_v0.tif : 0 – 5m
  - ESA_CH_S2_Auto_IDA_Opt5_v0.tif : 5m +
- ENC: CA473497 (DEPCNT and SOUNDG) (bathymetric DTM calculated with contour lines and soundings)

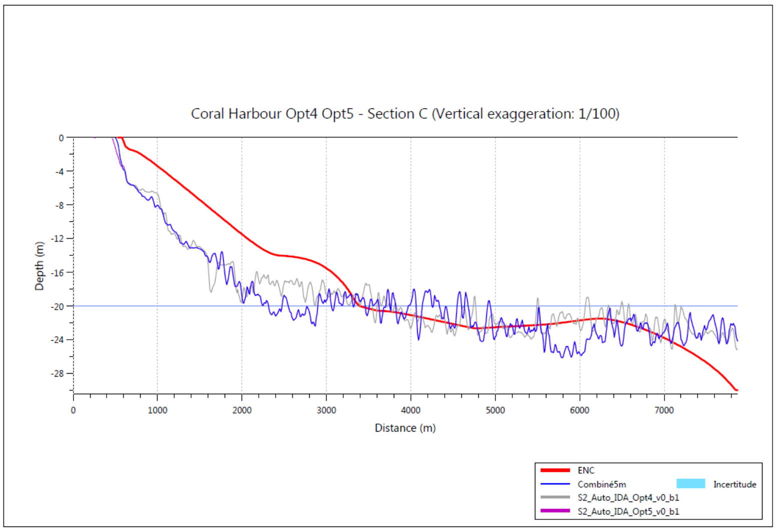
Findings:

- SDB's ***"Merge"*** results seem to reach a 20-24 m threshold




Coral Harbour Opt4 Opt5 - Section B (Vertical exaggeration: 1/100)
Depth (m)
0
-4
-8
-12
-16
-20
-24
-28
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Distance (m)
ENC
Combiné5m
S2_Auto_IDA_Opt4_v0_b1
S2_Auto_IDA_Opt5_v0_b1
Incertitude


Coral Harbour Opt4 Opt5 - Section A (Vertical exaggeration: 1/100)
Depth (m)
0
-4
-8
-12
-16
-20
-24
-28
0
1000
2000
3000
4000
5000
6000
7000
8000
Distance (m)
ENC
Combiné5m
S2_Auto_IDA_Opt4_v0_b1
S2_Auto_IDA_Opt5_v0_b1
Incertitude


Coral Harbour Opt4 Opt5 - Section C (Vertical exaggeration: 1/100)
Depth (m)
0
-4
-8
-12
-16
-20
-24
-28
0
1000
2000
3000
4000
5000
6000
7000
Distance (m)
ENC
Combiné5m
S2_Auto_IDA_Opt4_v0_b1
S2_Auto_IDA_Opt5_v0_b1
Incertitude

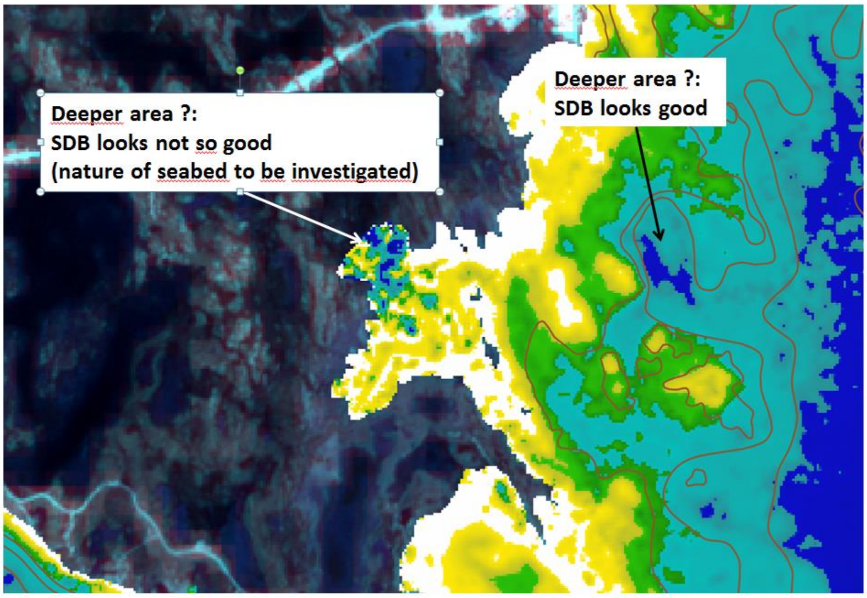
2.3. SDB processes remaining limits

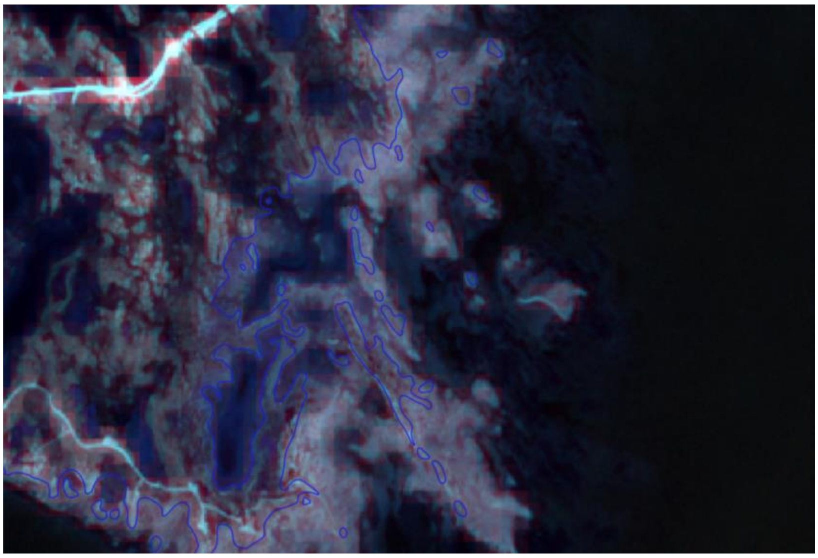
SDB processes still need to be improved as shown below.

As careless automatization may oversee some features, improved solutions must be found in the careful bespoke application of supervised processing methods by expert analysts and possibly in the use of complementary satellites images other than Sentinel-2. Careful examination of VHR Google and Bing images can be of great help,

The defaults of SDB process have been corrected to draw the chart (demonstrator).

<u>Case : areas where the nature of the sea floor (ie seagrass) is very different to the environment. In this example, depths can't be properly retrieved by the inversion model</u>





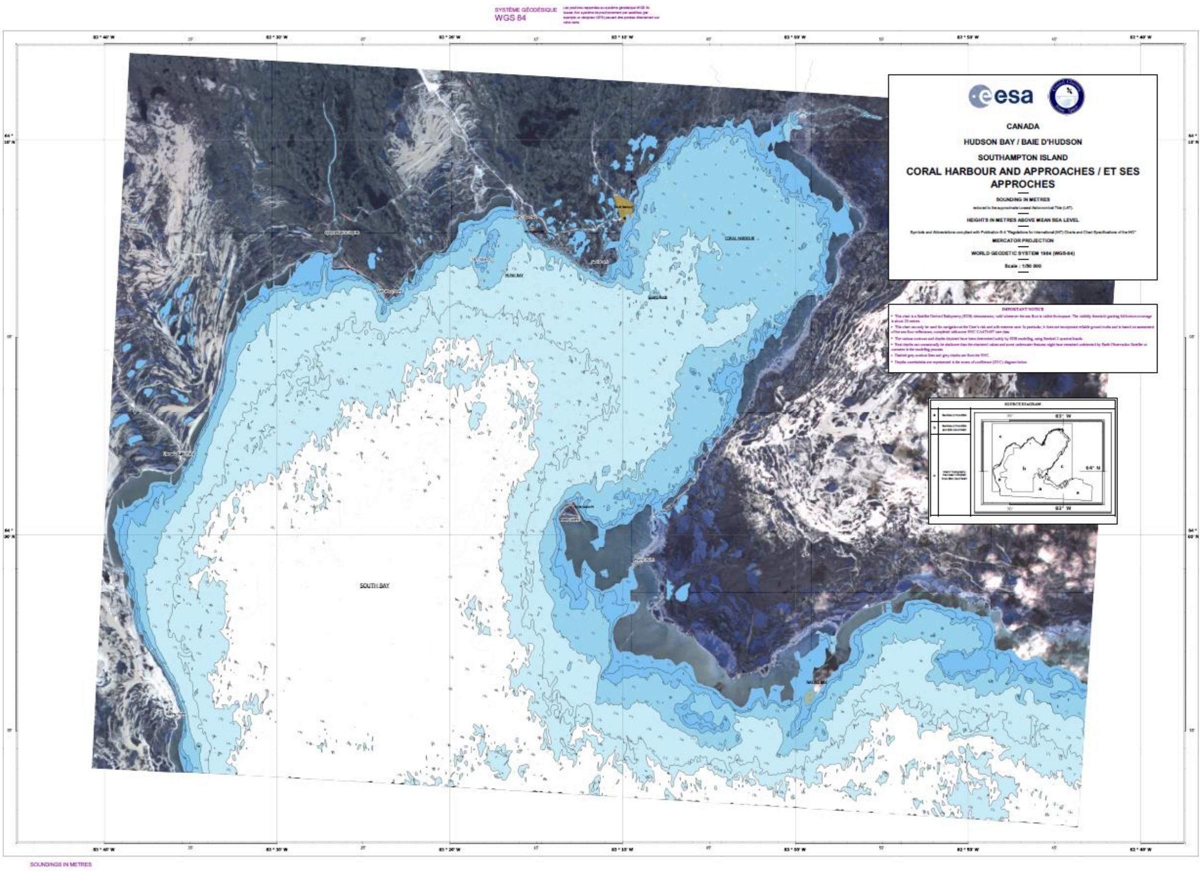
Dark areas (near the coast) interpreted wrongly by the model look deeper

3. Production of the SDB Demonstrator

3.1. Objectives (WP: 6, 8)

- ⇨ Produce a high-quality paper chart proving the compatibility between the IHO S-4 standards and the SDB model outputs.
- ⇨ Adapt the diagram of sources and ZOC to cater for SDB

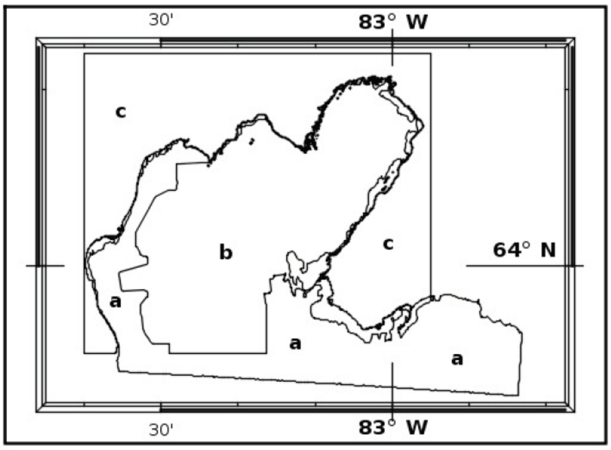
3.2. Demonstrator : “CoralHarbour_2019-09-11”



Source diagram

SOURCE DIAGRAM

a	Sentinel-2 from ESA
b	Sentinel-2 from ESA and ENC CA473497
c	Inland Topography has been compiled from ENC CA473497



4. Deliverables

Object	File's name
DTM	ESA_CH_S2_Auto_IDA_Opt4_v0.tif ESA_CH_S2_Auto_IDA_Opt5_v0.tif
Chart in "pdf" format (Adobe Acrobat Document)	CoralHarbour_2019-09-11
Chart in "GeoTiff" format (Image TIFF)	CoralHarbour_2019-09-11

APPENDIX – CORAL HARBOUR – CANADA

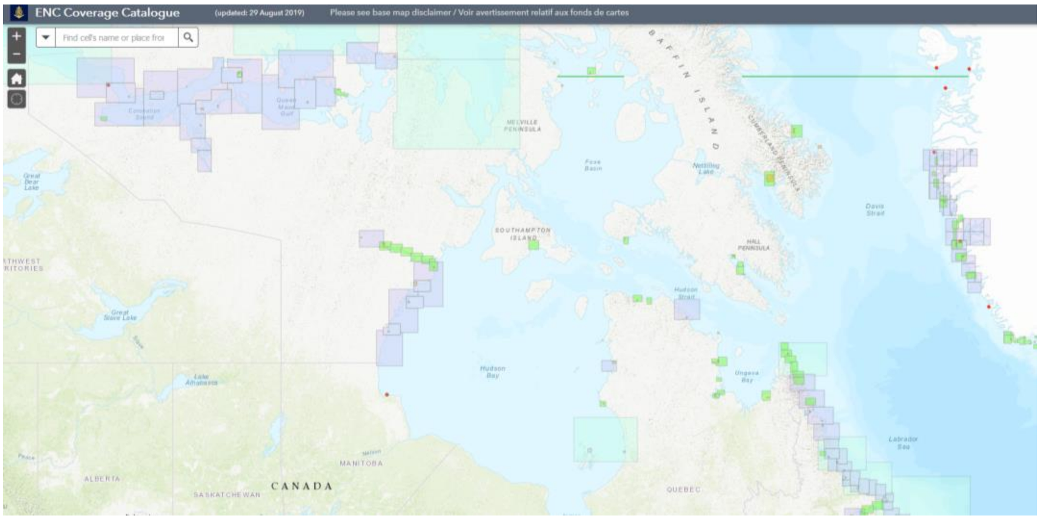
APPENDIX-1: Reference of charts and ENCs

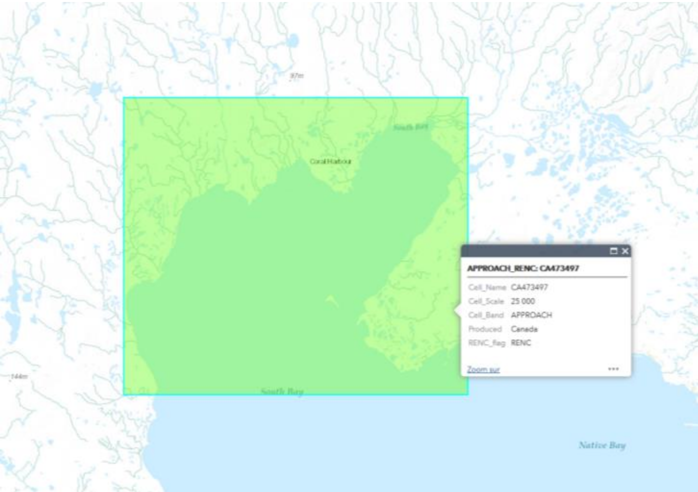
Canada – Baie d'Hudson – Coral Harbour

Electronic chart

ENC CA473497

http://iho.maps.arcgis.com/apps/webappviewer/index.html?id=06d967702c7f4094bbc5b4f8e485b712

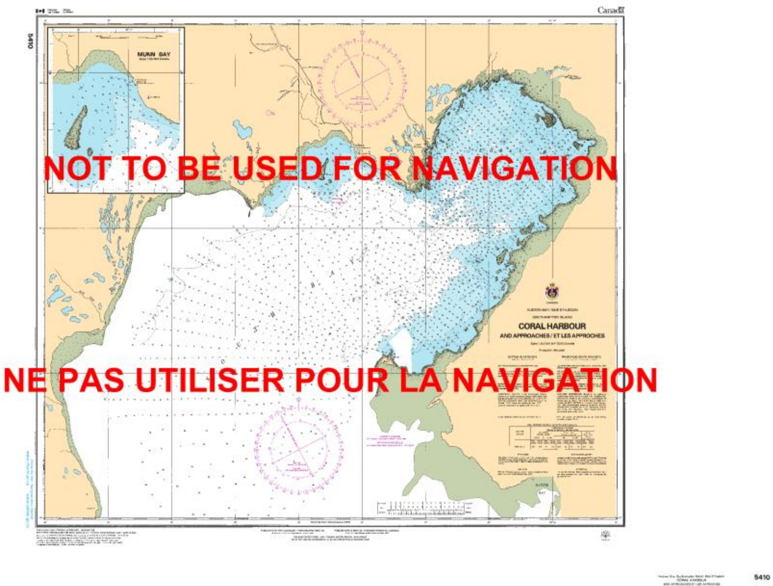




Paper chart

Carte papier 5410

- Coral Harbour and Approaches/et les approches
  - Numéro : 2019RM-5410-V3
  - Catégorie : NE
  - Échelle : 50000
  - Édition : 2019-06-07
- Overview as seen on Canadian Hydrographic Service:



APPENDIX-2: References : SDB model – Sentinel-2 images - Tides

The two DTMs produced for Coral Harbour have been produced by using twenty one individual models and the ***"Merge"*** following criteria:

- "ESA_CH_S2_Auto_IDA_Opt4_v0.tif" (Merged model using option 4 (distance weighted average method)]
- "ESA_CH_S2_Auto_IDA_Opt5_v0.tif" (Merged model using option 5 (range intersection method)

The Sentinel-2 images used by ***"Merge"*** are listed below:

	Name	Date(yyyy-mm-dd)	Time(H:M)	Tide (m)
1.	S2_20160813_T16WFS.tif	2016-08-13	17:13	1.75
2.	S2_20160902_T16WFS.tif	2016-09-02	17:13	3.20
3.	S2_20170629_T16WFS.tif	2017-06-29	17:13	0.45
4.	S2_20170706_T16WFS.tif	2017-07-06	16:58	3.50
5.	S2_20170712_T16WFS.tif	2017-07-12	17:19	2.00
6.	S2_20170727_T16WFS.tif	2017-07-27	17:18	1.00
7.	S2_20170816_T16WFS.tif	2017-08-16	17:18	1.10
8.	S2_20170910_T16WFS.tif	2017-09-10	17:19	1.50
9.	S2_20170919_T16WFS.tif	2017-09-19	16:59	3.50
10.	S2_20170924_T16WFS.tif	2017-09-24	17:00	1.55
11.	S2_20180716_T16WFS.tif	2018-07-16	16:58	1.50
12.	S2_20180717_T16WFS.tif	2018-07-17	17:19	0.85
13.	S2_20180719_T16WFS.tif	2018-07-19	17:08	0.42
14.	S2_20180724_T16WFS.tif	2018-07-24	17:08	1.40
15.	S2_20180726_T16WFS.tif	2018-07-26	17:01	2.85
16.	S2_20180806_T16WFS.tif	2018-08-06	17:19	1.40
17.	S2_20180902_T16WFS.tif	2018-09-02	17:08	1.20
18.	S2_20180904_T16WFS.tif	2018-09-04	17:00	1.30
19.	S2_20180907_T16WFS.tif	2018-09-07	17:10	1.50
20.	S2_20181009_T16WFS.tif	2018-10-09	17:02	3.94
21.	S2_20181014_T16WFS.tif	2018-10-14	17:02	1.30

APPENDIX-3: Bing map (2019)

https://www.bing.com/maps/aerial