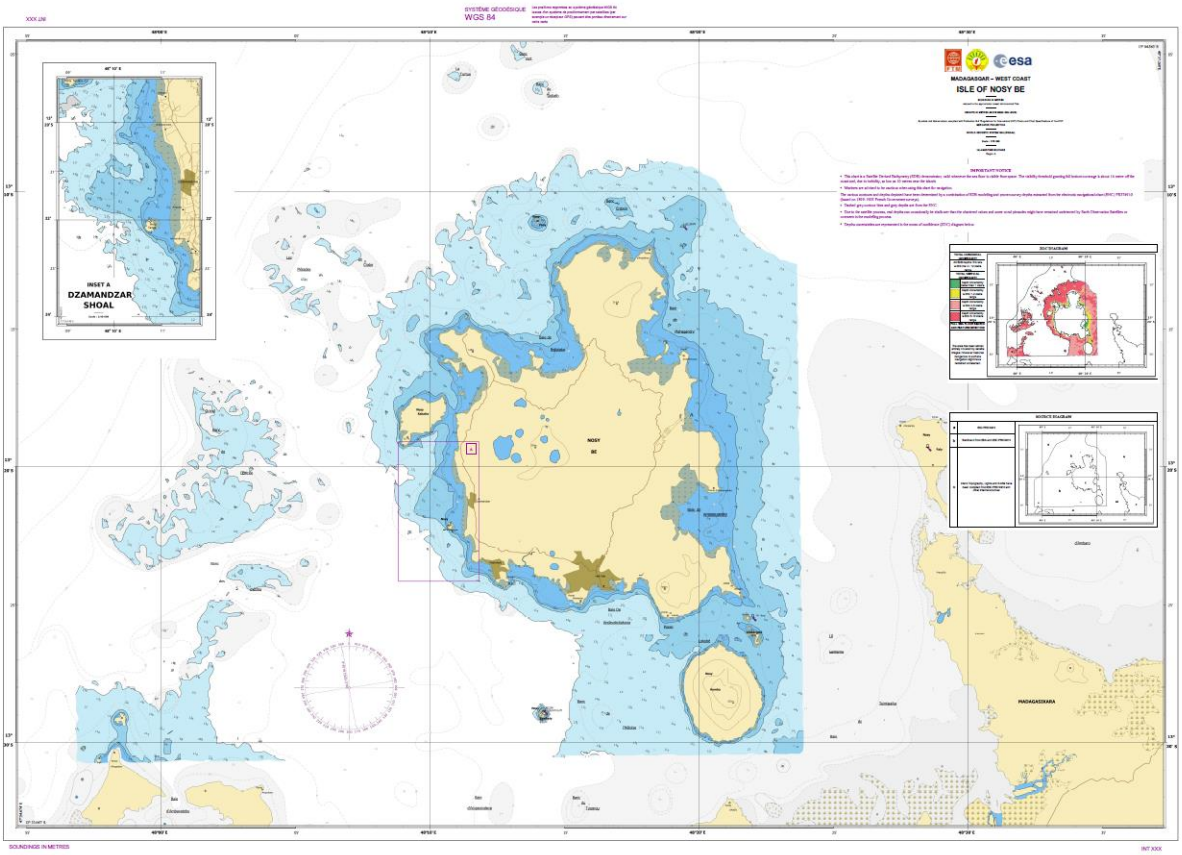
ANNEX B

Nosy Be



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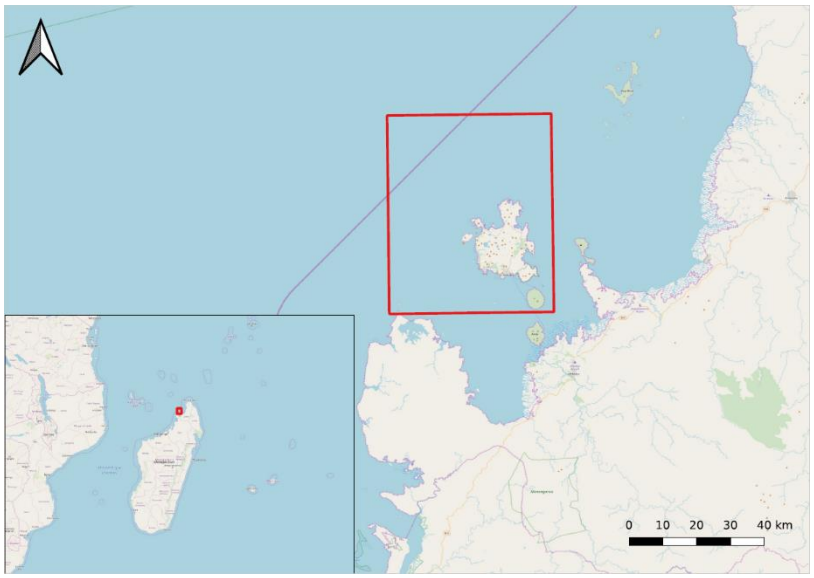
1. Background Information

1.1 Overview

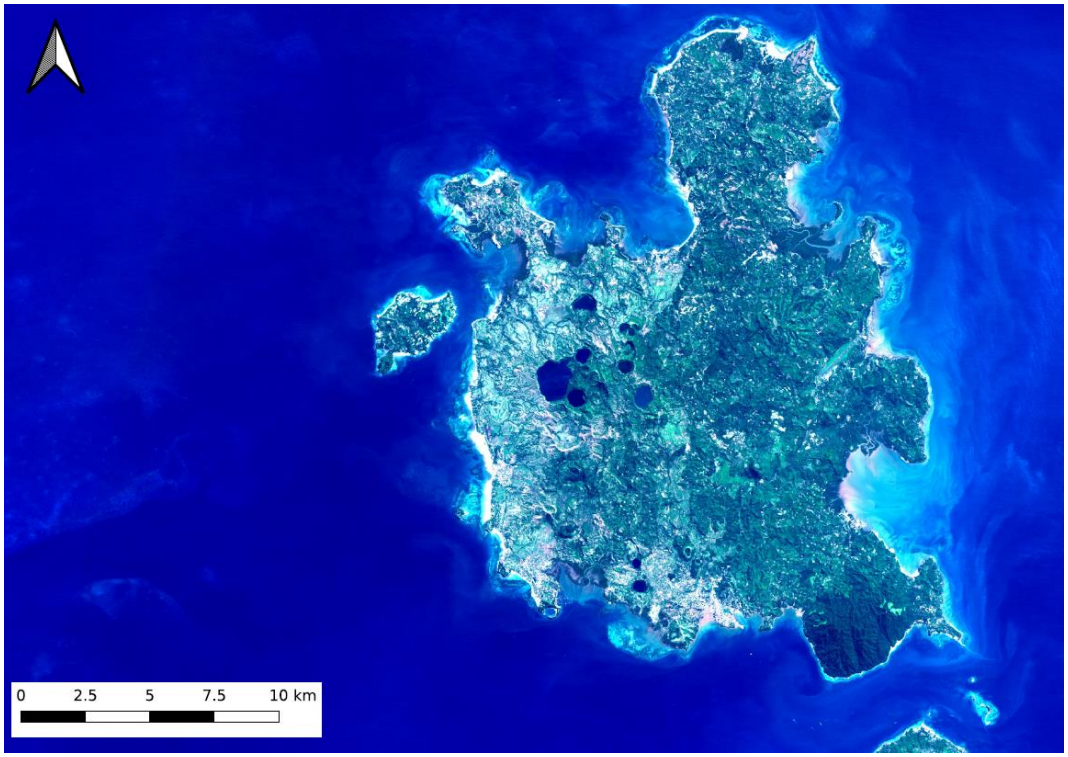
Nosy Be is an island located off the north western coast of Madagascar and is Madagascar's largest island with an area of 320.02 km^2.



Location of Nosy Be. Sentinel-2 tile is shown in red (T38LRL).

Nosy Be was chosen by ARGANS to be used as a research study site into the methodology behind ARGANS 'merge' method. Nosy Be provided the perfect location to show how this merge method can remove interference from artefacts such as sediment plumes.

The waters found off the east coast of Nosy Be typically experience high volumes of suspended sediment and turbulence. This is due to a number of factors that include estuaries along the eastern coastline and high tide ranges (over 3 m) which contribute towards resuspended sediment from the seabed (figure below).



This image shows a Sentinel-2 L1C True Colour Composite of Nosy Be highlighting the high rates of suspended sediment that is typically observed along the East coast compared to the relatively calm West coast.

The aim of carrying out this investigation over Nosy Be was to assess how Sentinel-2's time series can be used to remove the noise and interference of the sediment plumes from the large data base of imagery available. By using ARGANS method the user does not have to wait for the one 'perfect image' but instead can use the large database to extract only the relevant information from each single image using the merge.

1.2 Methodology

The study site for Nosy Be lies within one Sentinel-2 tile path as shown in § 1.1 (T38LRL). For this study site 53 L1C Sentinel-2 tiles were downloaded from ESA Copernicus SciHub. These images were selected after careful visual inspection taking into account for artefacts such as clouds. After a second round of quality control 50 images were used to create the SDB models used within the ARGANS merge method.

All 50 mages were processed using IDA to produce the bathymetry model before being merged. As already mentioned, Nosy Be experiences large tidal changes and this was evident throughout the

Sentinel-2 images. To reduce the effect of tide a low tide mask was applied to all images that were required. This involved computing a threshold within the near infra-red band for land and water and ensuring only water was processed within IDA and therefore removing all low tide effects from the images. To assess which merge method to use for Nosy Be all five were tested. The results were then compared to ensure that only the best result was used within the investigation.

1.3 Main results

After the bathymetry was produced for all 50 models, they were inspected visually to ensure that no anomalies were included within the results. This test was to ensure that all models had been processed correctly and that the atmospheric correction applied had ensured that the result of the bathymetry aligned with the expected results.

All five merge methods were tested before selecting what was deemed the best fitting model. This test requires using the true colour composite images to ensure that any artefacts such as sand banks visible to the eye were incorporated within the model. After assessing the five methods the minimum distance weighted model was approved to be the most accurate and this was the model that was used to produce the final chart.

1.4 References

Inputs and references are listed at the appendix 1 and 2 for clarity. They include the following:

- References related to SDB :
    - New SDB model : “ESA_NB_S2_Auto_IDA_V2” (merge of 50 Sentinel-2 images)
    - List of used Sentinel-2 images
- References related to existing official charts and ENCs:
    - Shom charts N° 5264 and 5128
    - ENC N° FR374910 (related to chart 7491)
    - Nota: the soundings depicted on these charts are originated mainly from a lead line survey performed between 1887 and 1910.

1.4.1 Project Data files

The Project data files listed at the appendix, e.g. ESA_NB_S2_AUTO_IDA_V2 are in the following format:

ESA + Site (e.g. NB for Nosy Be) + Satellite Processing (e.g. AUTO for automatized) + SDB software (e.g. IDA, ICEC, etc.) + SDB model (e.g.V2).

1.4.2 SDB references

- SDB model reference "ESA_NB_S2_Auto_IDA_V2" obtained by selecting 53 Sentinel-2 images, reduced to a 50 images dataset.
- List of Sentinel-2 images used by this demonstrator.

1.4.3 Existing official charts' and ENCs' references

- Shom charts 5264 and 5128.
- The FR374910 ENC, linked to Shom chart 7491.

Note 1: the soundings depicted on these charts are originated mainly from French Government surveys performed between 1887 and 1910. Admittedly, the values yielded by such professional lead line surveys are reliable and as precise as those measured by echosounders, albeit much less dense.

Note 2: the combination of discreet lead line data and full coverage offered by satellite can be very effective in providing a continuous DTM set on proven and reliable depth measurements.

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 charting. WPs.

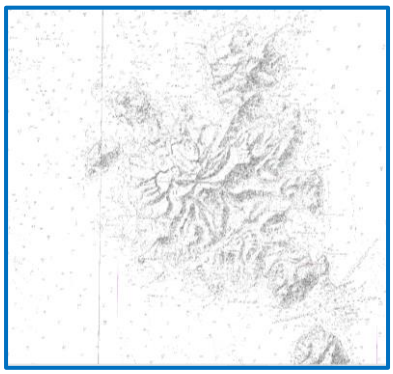
2.2. Cartographic Qualification by comparison against paper charts

2.2.1. Remarks

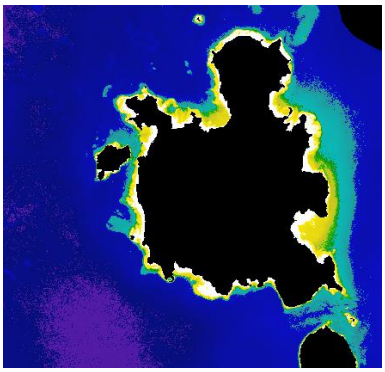
i. This comparison is somewhat basic compared to the one that could have been done against fair sheets, should these had been available.

ii. The Demonstrator V2 was chosen for no other reason that it was availability at the time of the comparison

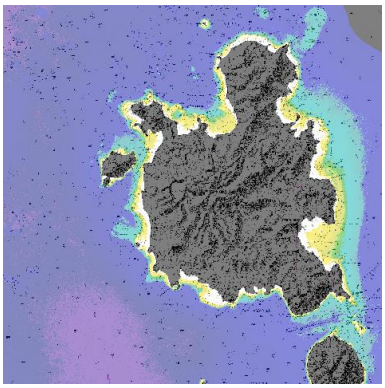
2.2.2. Whole area



Shom Chart 5264 (1908 edition)



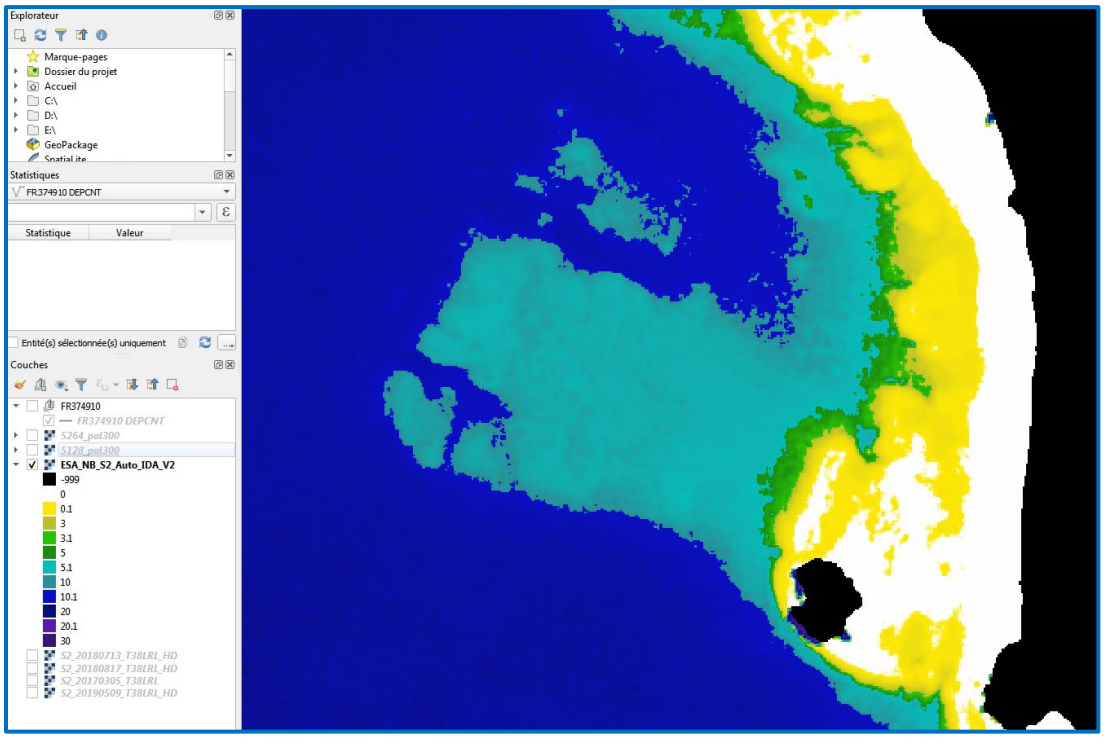
SDB Demonstrator V2



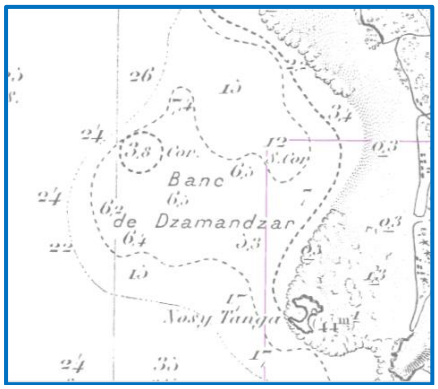
SDB V2 + Shom Chart 5264

- As expected, SDB only covers a narrow area around the island where the sea floor is visible from space
- The whole area is visible since clouds have been removed from this "Perfect Image" obtained by combining 50 Sentinel-2 scenes.

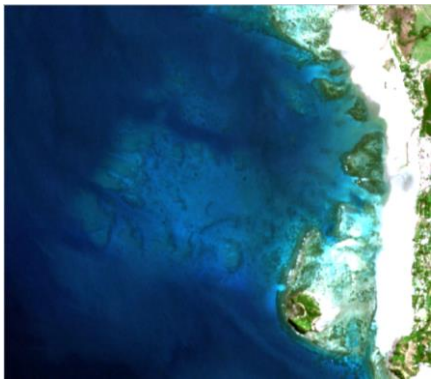
2.2.3. Dzamandzar Shoal



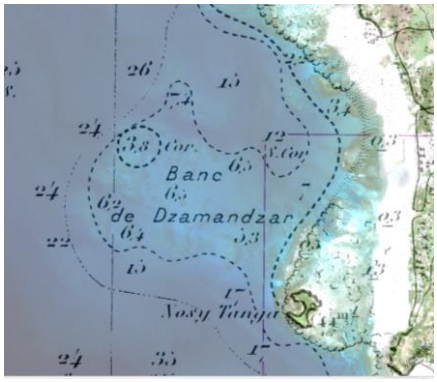
SDB Demonstrator V2



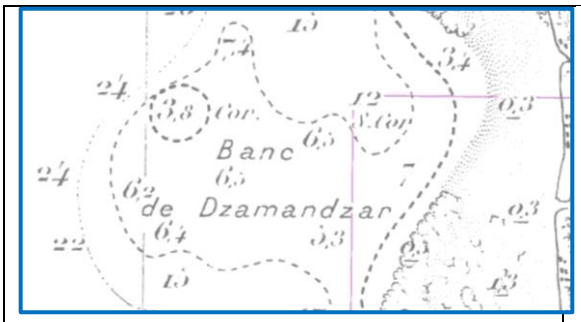
Shom Chart 5264



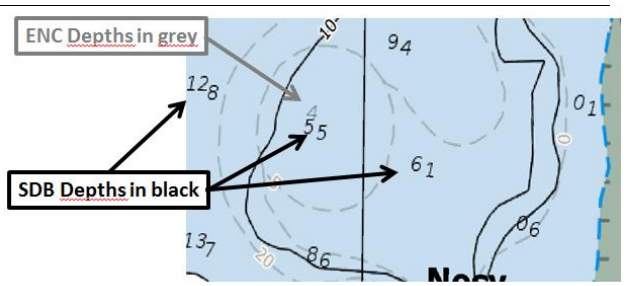
Sen-2 scene S2_20180713_T38LRL



SDB V2 + Shom Chart 5264



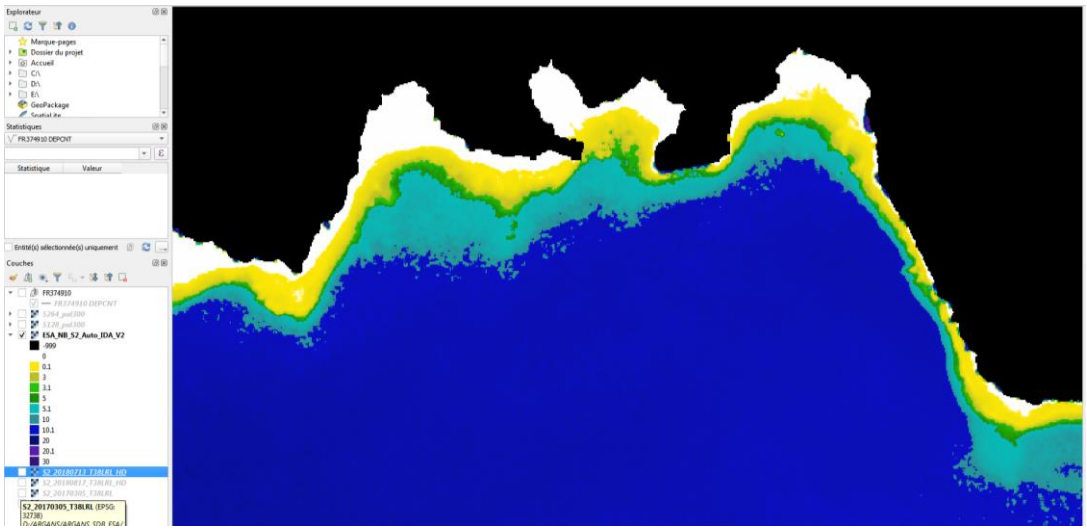
Shom Chart 5264



Shom ENC (grey) and SDB

- SDB depicts clearly the Dzamandzar Shoal ("*Banc Dzamandzar* " in French), which depths on the chart are comprised between 5 and 10 m, culminating at 3.8 metre (4 metre on the ENC).
- 5,5 m on SDB in the centre (SDB Depths in black) : represent more the average depths of the area (6,2 m to 3,8m) than the culminating point of 3,8 m (4 on ENC).
- SDB's depths beyond 10 m seem wrong (impact of turbidity higher close to the island than off the coast).
- As a consequence, satellite depths are deemed by the analyst to be reliable up to 10 m.

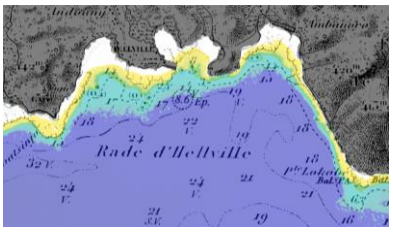
2.2.4. Hell-Ville1 Roads



SDB Demonstrator V2

Shom Chart 5128 (1956 edition)

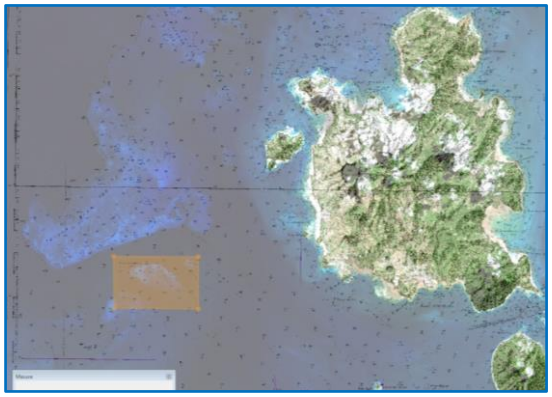
Sen-2 scene S2_20180713_T38LRL



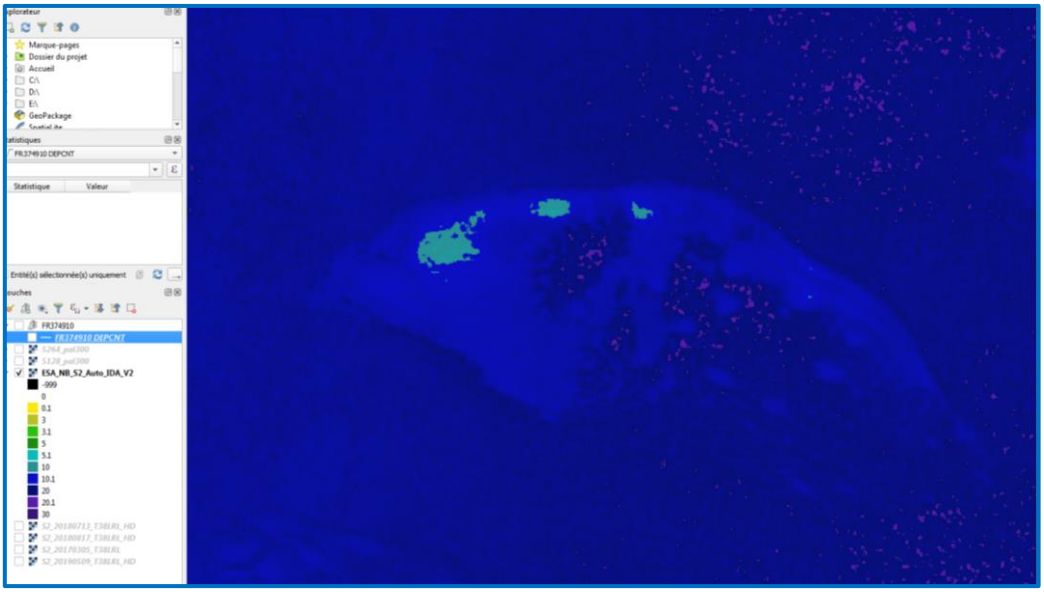
SDB + Shom Chart 5128

- The roads' depths and dangers are well represented on the Sen-2 image
- Satellite depths are deemed by the analyst to be reliable up to 10 metres

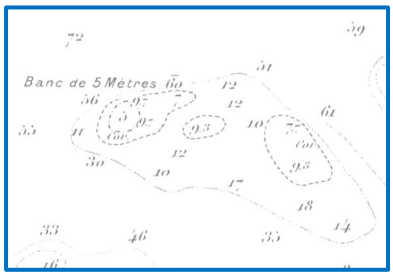
2.2.5. Five-Metre Shoal ("Banc de 5 mètres" in French)



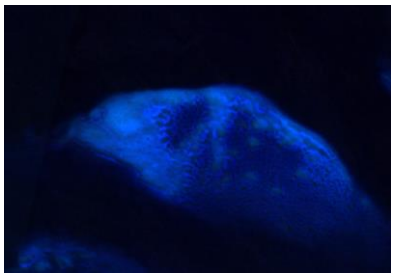
[1] Named after Admiral de Hell (1783 - 1864), former Governor of *Ile Bourbon*, now *La Réunion*, and later Director of the French Hydrographic Office.



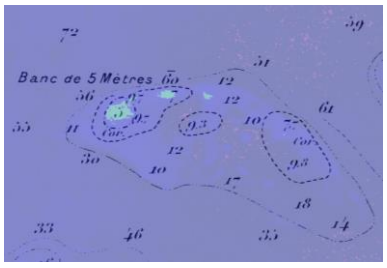
SDB Demonstrator V2



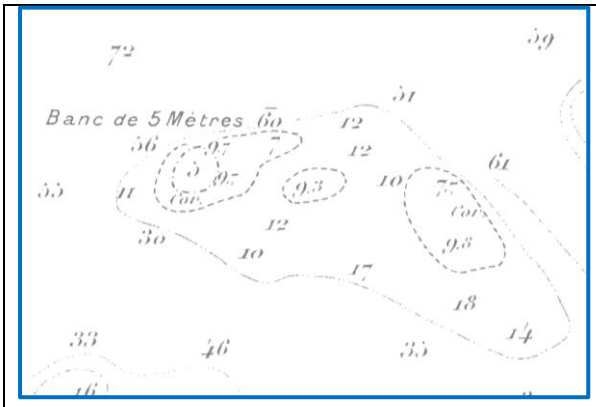
Shom Chart 5264



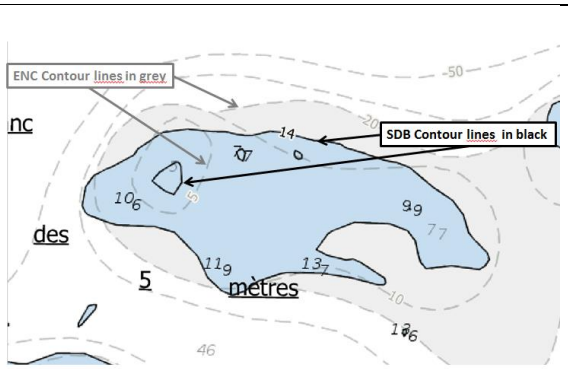
Sentinel-2 scene S2_20180713_T38LRL



SDB V2 + Shom Chart 5264

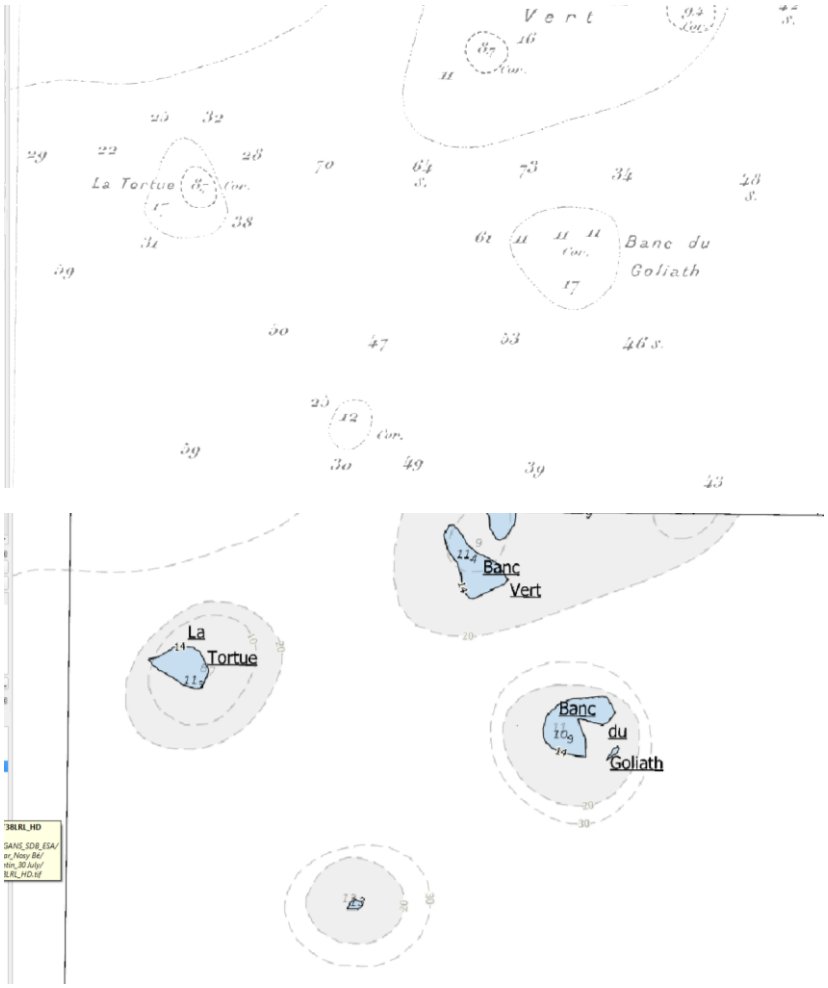


Shom Chart 5264



Shom ENC (grey) and SDB

2.2.6. La Tortue – Banc Vert – Banc du Goliath

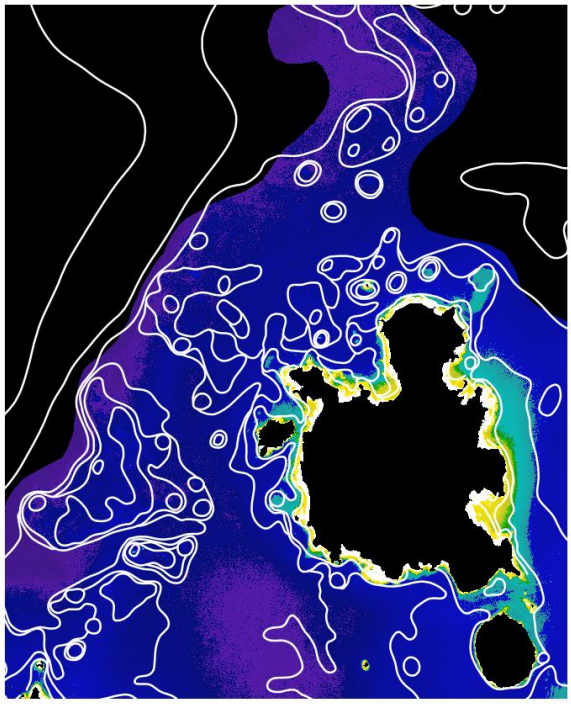


These shoals are well represented by SDB. Some comparison on depths

	Chart - ENC	SDB
La Tortue	8,7	11,3
Banc Vert	9	11,4
Banc du Goliath	11	10,9
Shoal in the South	12	13

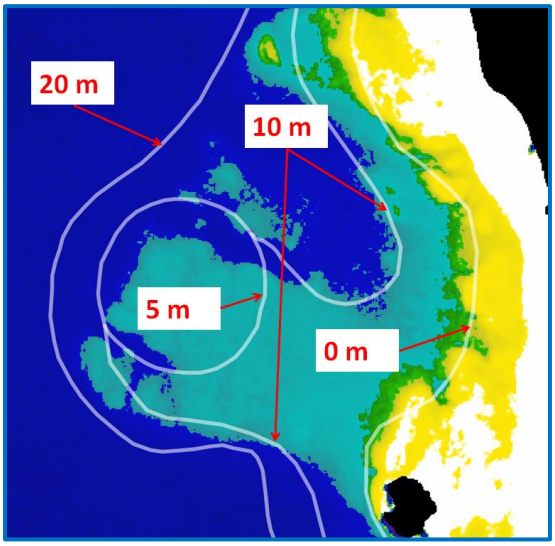
2.3. Cartographic Qualification by comparison against ENCs

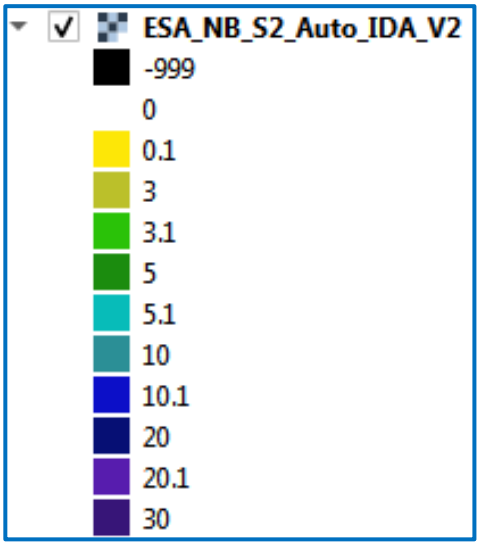
Being based on the same data as paper charts, ENCs drawings might differ very slightly but should reach the same conclusions. However, as their contours are already digitized, they are more convenient to be exported to the SDB Demonstrators for comparisons.

3. 

Comparison between SDB Demonstrator and ENC: FR374910 (DEPCNT)

The ENC white contours are overlaid onto the ENC





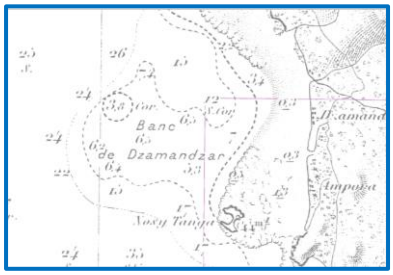
Thanks to the satellite total coverage, Hydrographers/Analysts are entitled to assume that the Demonstrator's contours are significantly more accurate than those of the ENC wherever the seafloor is visible.

2.4. Comparison between a model produced with a single Sen-2 image and a “Perfect Image

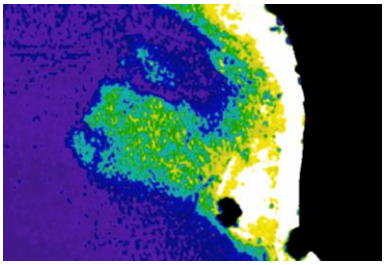
2.4.1. Selection of SDB models

The comparison has been performed on the two SDB models obtained by processing respectively a single very good image ESA_NB_S2_Auto_IDA_V0 and the “Perfect Image” obtained by merging 53 scenes ESA_NB_S2_Auto_IDA_V2.

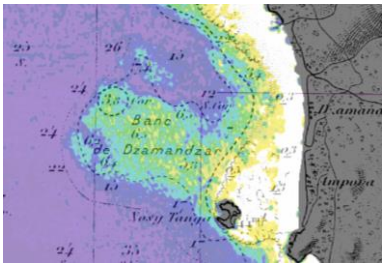
2.4.2. Dzamandzar shoal



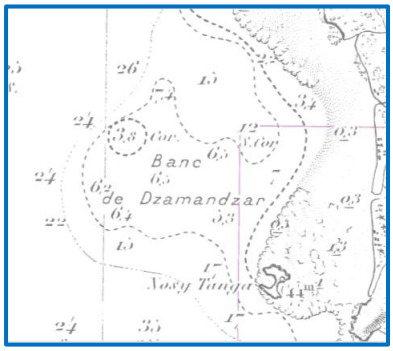
Shom Chart 5264



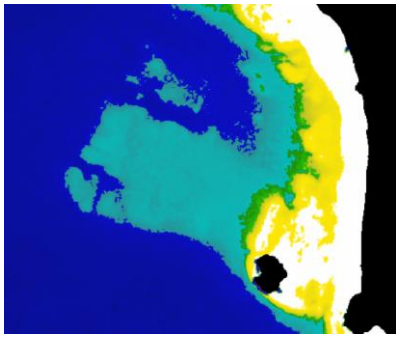
V0 SDB Model
Single good image



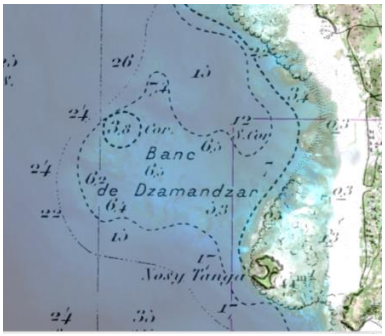
V0 + Shom Chart 5264



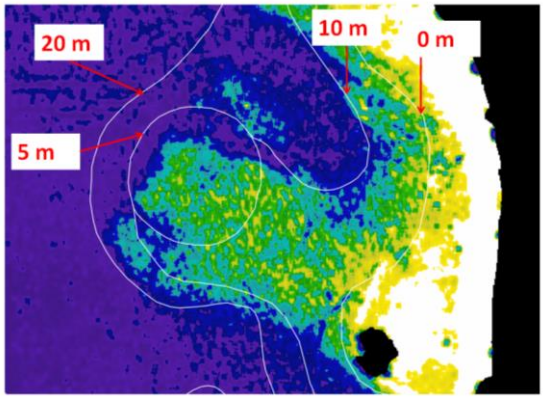
Shom Chart 5264



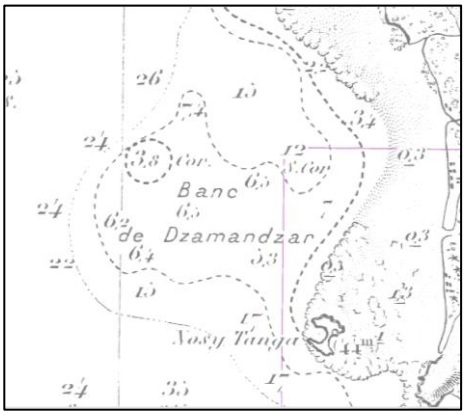
V2 SDB Model
“Perfect Image”



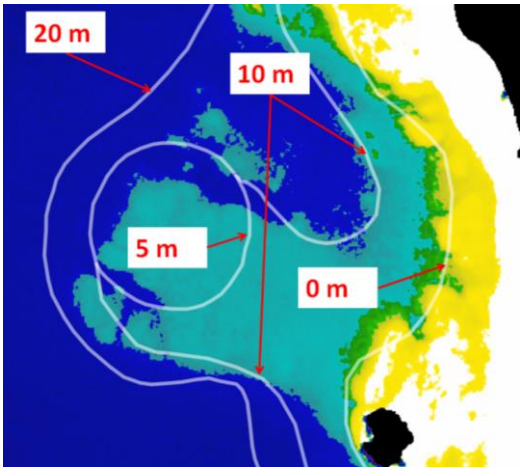
V2 + Shom Chart 5264



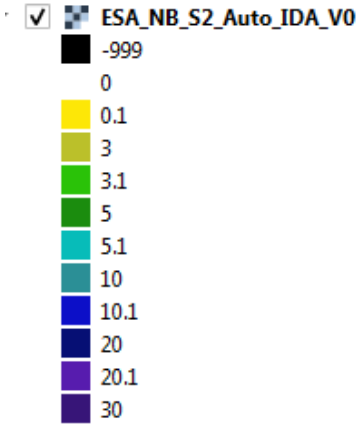
V0 single good image SDB Model



Shom Chart 5264



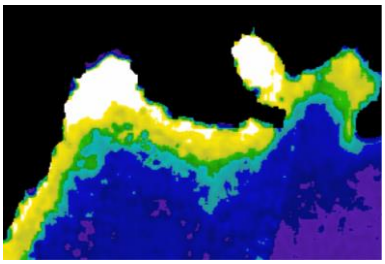
V2 SDB Model "Perfect Image"



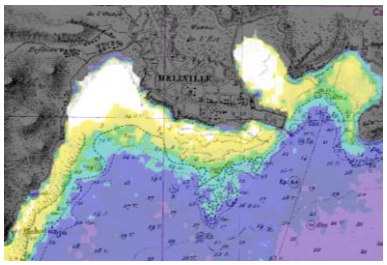
Depths colour codes

2.4.3. Hell-Ville roads

Shom Chart 5128 (1956 edition)

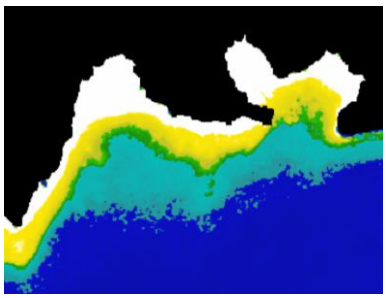


V0 SDB Model

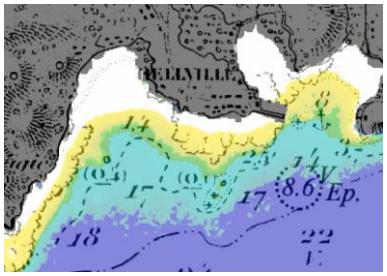


V0 SDB + Shom Chart 5128

Shom Chart 5128 (1956 edition)



V2 SDB Model "Perfect Image"



V2 SDB Model + Shom Chart 5128

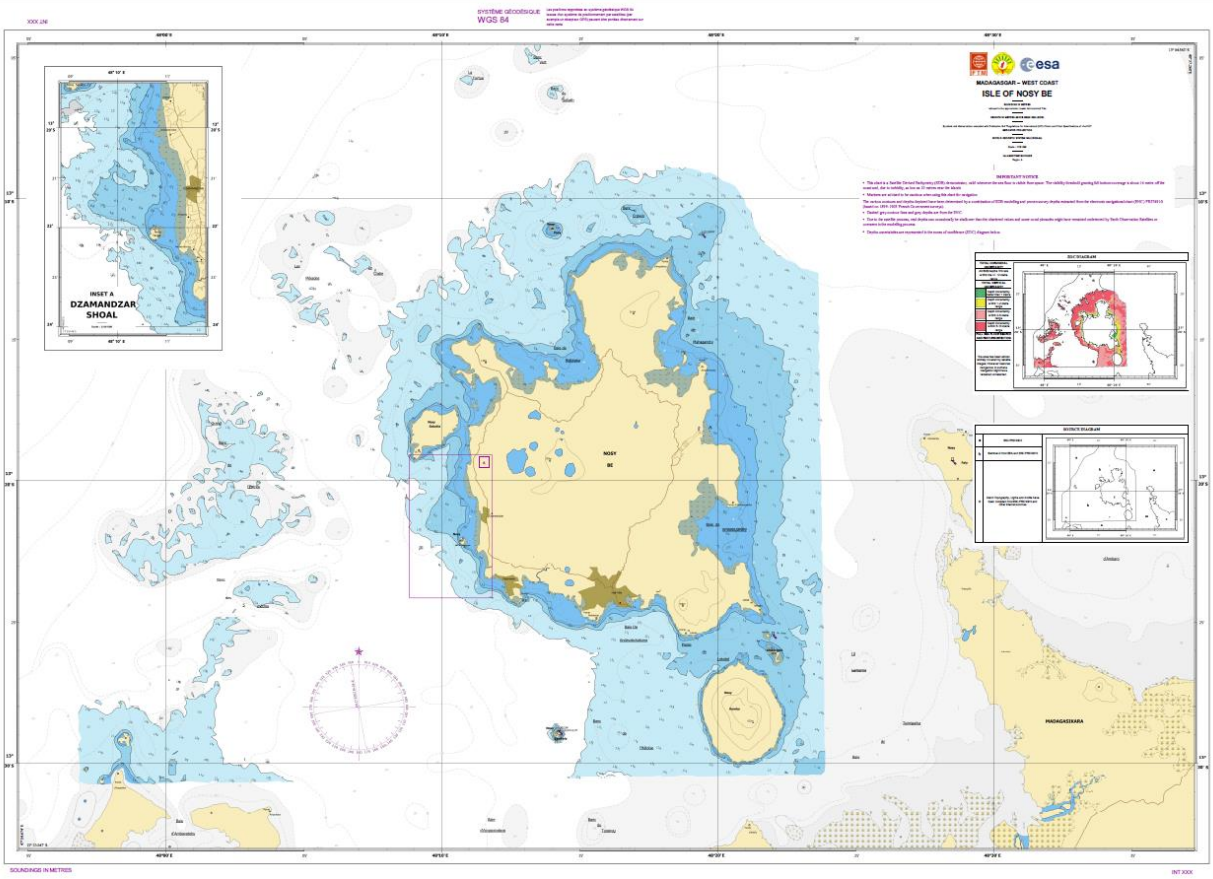
3. Production of the SDB Demonstrator

3.1. Objectives (WP: 6, 8)

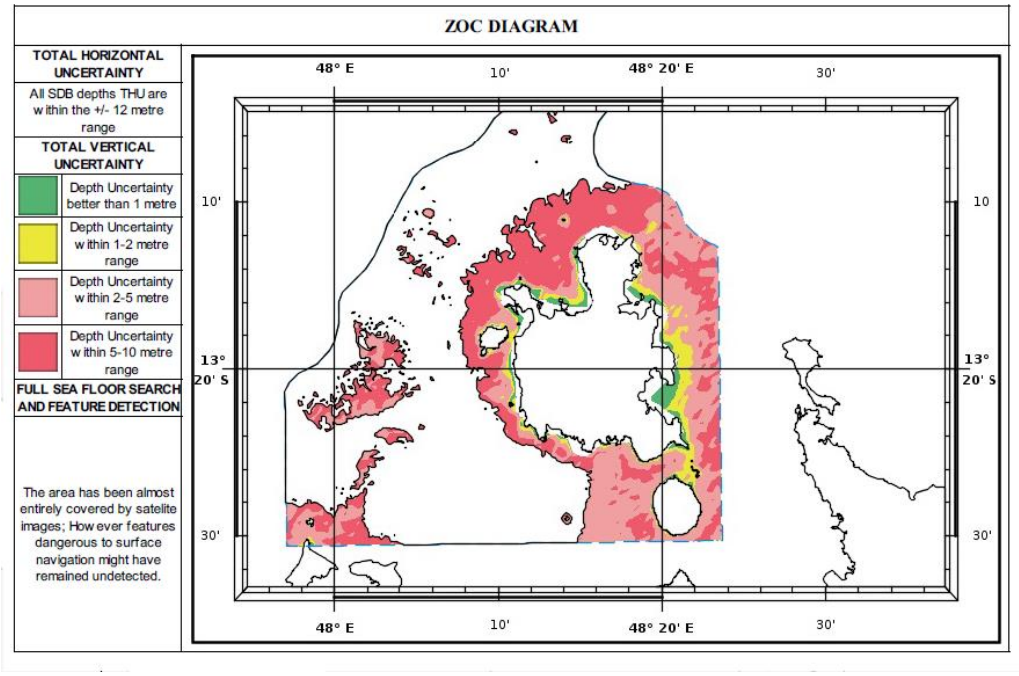
- ⇨ Produce a high-quality paper chart proving the compatibility between the IHO S-4 standards and the SDB model outputs.
- ⇨ Adapt the diagram of sources and ZOC to cater for SDB

- ⇨ If the demonstrator is confirmed to be superior to the 1903 Shom jalopy as expected from the preliminary analysis, develop a new wording to reflect both the improvements brought by Sentinel-satellites and the limits of SDB to safety of navigation.
- ⇨ Prepare the ground for a change of approach in uncharted coastal areas, both by Mariners and Hydrographic Offices

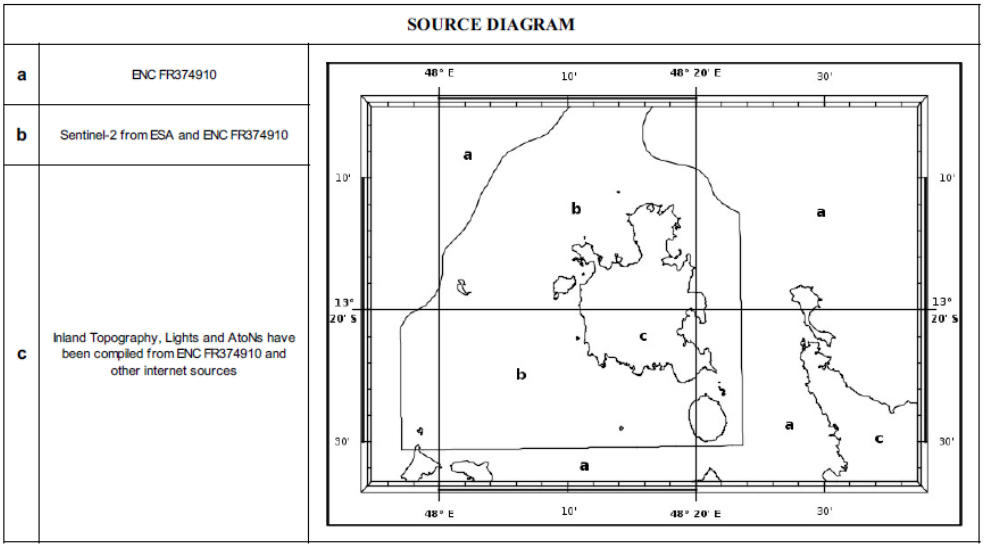
3.2. Demonstrator : “Nosy Be-7000-2019-08-27”



ZOC :



Source diagram



4. Deliverables

Object	File's name
DTM	ESA_NB_S2_AUTO_IDA_V2
Chart in "pdf" format (Adobe Acrobat Document)	Nosy Be-7000-2019-08-27
Chart in "GeoTiff" format (Image TIFF)	Nosy Be-7000-2019-08-27

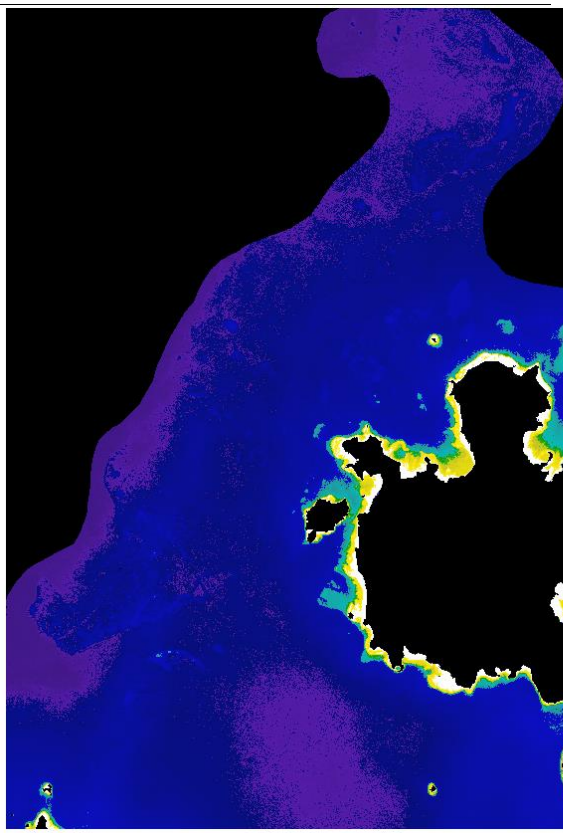
APPENDIX – NOSY BE – MADAGASCAR

APPENDIX-1: SDB models and Sentinel-2 images references

V2: References:

- File : “ESA_NB_S2_Auto_IDA_V2”

Sentinel 2 : S2_20180713_T38LRL



SDB : ESA_NB_S2_Auto_IDA_V2

Images are listed as follows:
1 : S2_20180504_T38LRL/S2_20180504_T38LRL_4_BathyZ.tif
2 : S2_20170613_T38LRL/S2_20170613_T38LRL_4_BathyZ.tif
3 : S2_20180628_T38LRL/S2_20180628_T38LRL_4_BathyZ.tif
4 : S2_20160906_T38LRL/S2_20160906_T38LRL_4_BathyZ.tif
5 : S2_20180419_T38LRL/S2_20180419_T38LRL_4_BathyZ.tif
6 : S2_20170623_T38LRL/S2_20170623_T38LRL_4_BathyZ.tif
7 : S2_20180603_T38LRL/S2_20180603_T38LRL_4_BathyZ.tif
8 : S2_20170807_T38LRL/S2_20170807_T38LRL_4_BathyZ.tif
9 : S2_20180618_T38LRL/S2_20180618_T38LRL_4_BathyZ.tif

10 : S2_20180514_T38LRL/S2_20180514_T38LRL_4_BathyZ.tif
11 : S2_20180613_T38LRL/S2_20180613_T38LRL_4_BathyZ.tif
12 : S2_20160827_T38LRL/S2_20160827_T38LRL_4_BathyZ.tif
13 : S2_20170708_T38LRL/S2_20170708_T38LRL_4_BathyZ.tif
14 : S2_20170414_T38LRL/S2_20170414_T38LRL_4_BathyZ.tif
15 : S2_20180524_T38LRL/S2_20180524_T38LRL_4_BathyZ.tif
16 : S2_20170718_T38LRL/S2_20170718_T38LRL_4_BathyZ.tif
17 : S2_20190218_T38LRL/S2_20190218_T38LRL_4_BathyZ.tif
18 : S2_20190504_T38LRL/S2_20190504_T38LRL_4_BathyZ.tif
19 : S2_20181225_T38LRL/S2_20181225_T38LRL_4_BathyZ.tif
20 : S2_20160718_T38LRL/S2_20160718_T38LRL_4_BathyZ.tif
21 : S2_20160509_T38LRL/S2_20160509_T38LRL_4_BathyZ.tif
22 : S2_20170906_T38LRL/S2_20170906_T38LRL_4_BathyZ.tif
23 : S2_20180713_T38LRL/S2_20180713_T38LRL_4_BathyZ.tif
24 : S2_20180807_T38LRL/S2_20180807_T38LRL_4_BathyZ.tif
25 : S2_20190320_T38LRL/S2_20190320_T38LRL_4_BathyZ.tif
26 : S2_20180608_T38LRL/S2_20180608_T38LRL_4_BathyZ.tif
27 : S2_20190509_T38LRL/S2_20190509_T38LRL_4_BathyZ.tif
28 : S2_20160628_T38LRL/S2_20160628_T38LRL_4_BathyZ.tif
29 : S2_20160817_T38LRL/S2_20160817_T38LRL_4_BathyZ.tif
30 : S2_20180802_T38LRL/S2_20180802_T38LRL_4_BathyZ.tif
31 : S2_20160330_T38LRL/S2_20160330_T38LRL_4_BathyZ.tif
32 : S2_20180228_T38LRL/S2_20180228_T38LRL_4_BathyZ.tif
33 : S2_20180911_T38LRL/S2_20180911_T38LRL_4_BathyZ.tif
34 : S2_20170911_T38LRL/S2_20170911_T38LRL_4_BathyZ.tif
35 : S2_20170723_T38LRL/S2_20170723_T38LRL_4_BathyZ.tif
36 : S2_20160728_T38LRL/S2_20160728_T38LRL_4_BathyZ.tif
37 : S2_20160519_T38LRL/S2_20160519_T38LRL_4_BathyZ.tif
38 : S2_20180519_T38LRL/S2_20180519_T38LRL_4_BathyZ.tif
39 : S2_20180429_T38LRL/S2_20180429_T38LRL_4_BathyZ.tif
40 : S2_20180718_T38LRL/S2_20180718_T38LRL_4_BathyZ.tif
41 : S2_20181011_T38LRL/S2_20181011_T38LRL_4_BathyZ.tif
42 : S2_20190519_T38LRL/S2_20190519_T38LRL_4_BathyZ.tif
43 : S2_20160807_T38LRL/S2_20160807_T38LRL_4_BathyZ.tif
44 : S2_20180218_T38LRL/S2_20180218_T38LRL_4_BathyZ.tif
45 : S2_20180223_T38LRL/S2_20180223_T38LRL_4_BathyZ.tif
46 : S2_20180926_T38LRL/S2_20180926_T38LRL_4_BathyZ.tif
47 : S2_20170305_T38LRL/S2_20170305_T38LRL_4_BathyZ.tif
48 : S2_20180906_T38LRL/S2_20180906_T38LRL_4_BathyZ.tif
49 : S2_20180817_T38LRL/S2_20180817_T38LRL_4_BathyZ.tif
50 : S2_20170802_T38LRL/S2_20170802_T38LRL_4_BathyZ.tif

APPENDIX-2: Reference of charts and ENC from Shom

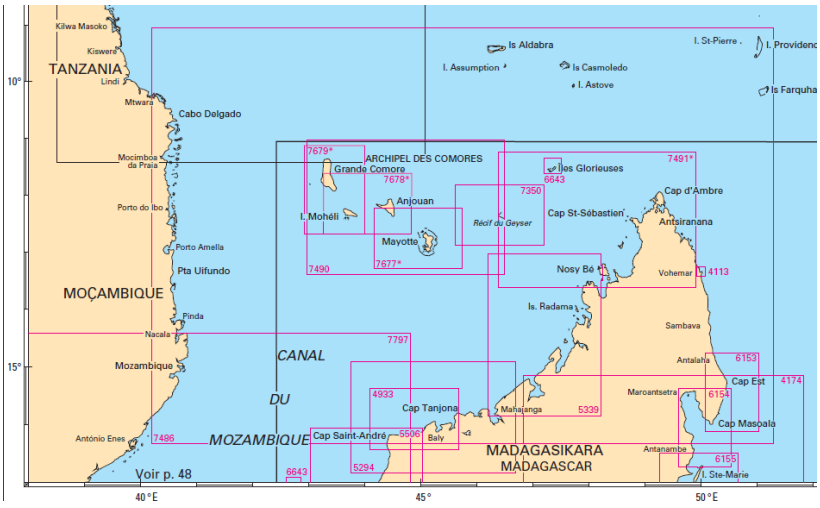
Madagascar – Nosy Be

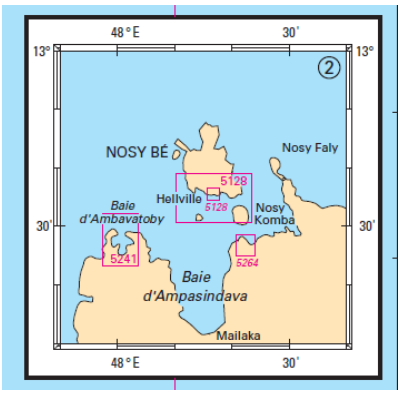
The most useful Shom Charts are : 5264, 5128

N° Shom (FR) CM et GeoTiff	N° INT	French Title	Scale	Edition	ENC ?
5264		De la Pointe d'Andemby à la Pointe d'Angadoka	1 : 100 000	1908	NO
5128		Partie Sud de Nosi-bé	1 : 25 000	1956	NO

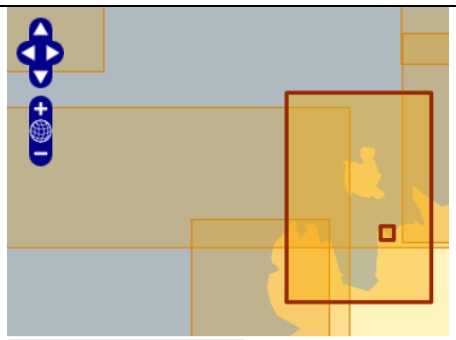
Less intersting chart except that there is an ENC : chart 7491) (ENC (FR374910)

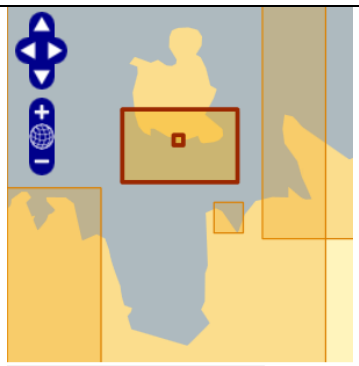
N° Shom (FR) CM et GeoTiff	N° INT	Titre	Echelle	Edition	ENC ?
7491	7720	De Nosy Bé à la baie d'Antsiranana	1 : 350 000	1998	YES

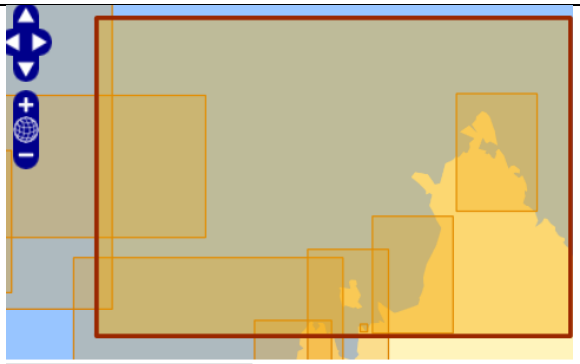




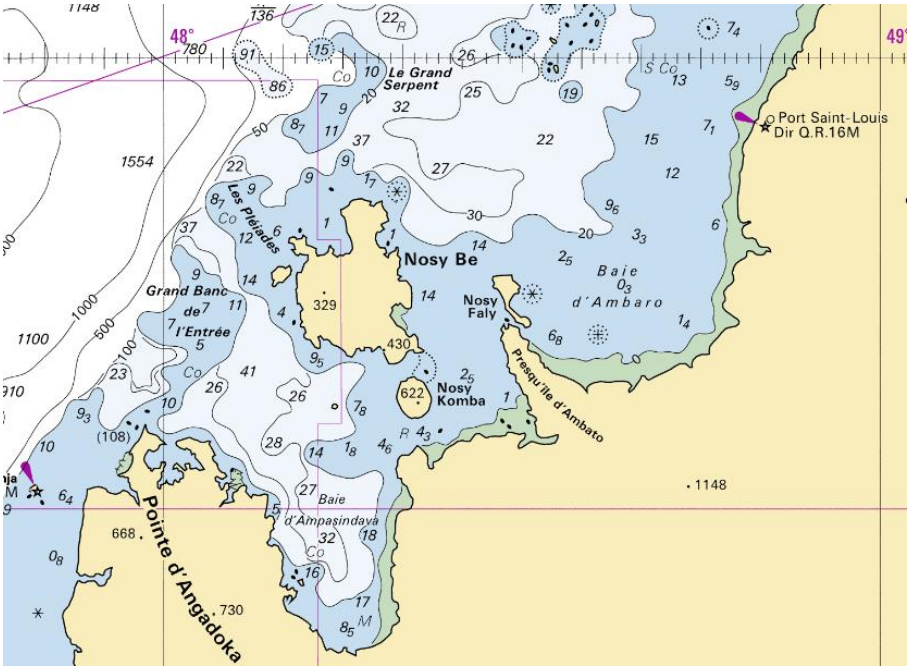
Shom GeoTiff





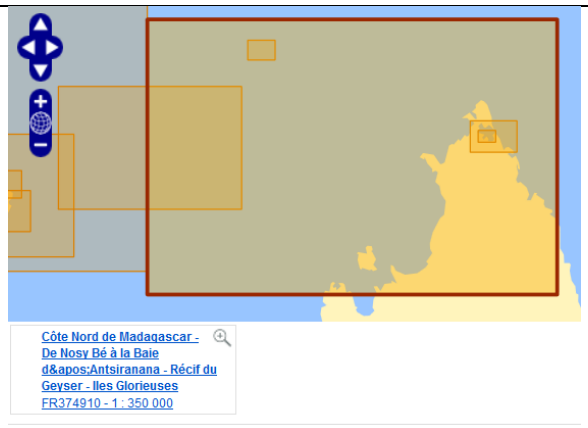


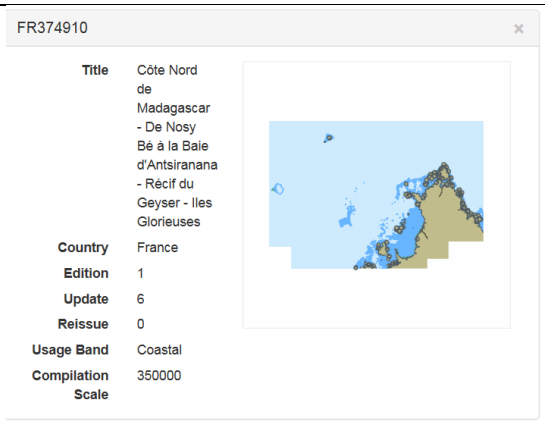
Excerpt of CM 7486 GeoTiff (scale : 1 : 1 080 000, *Canal Mozambique Partie nord*)



ENC

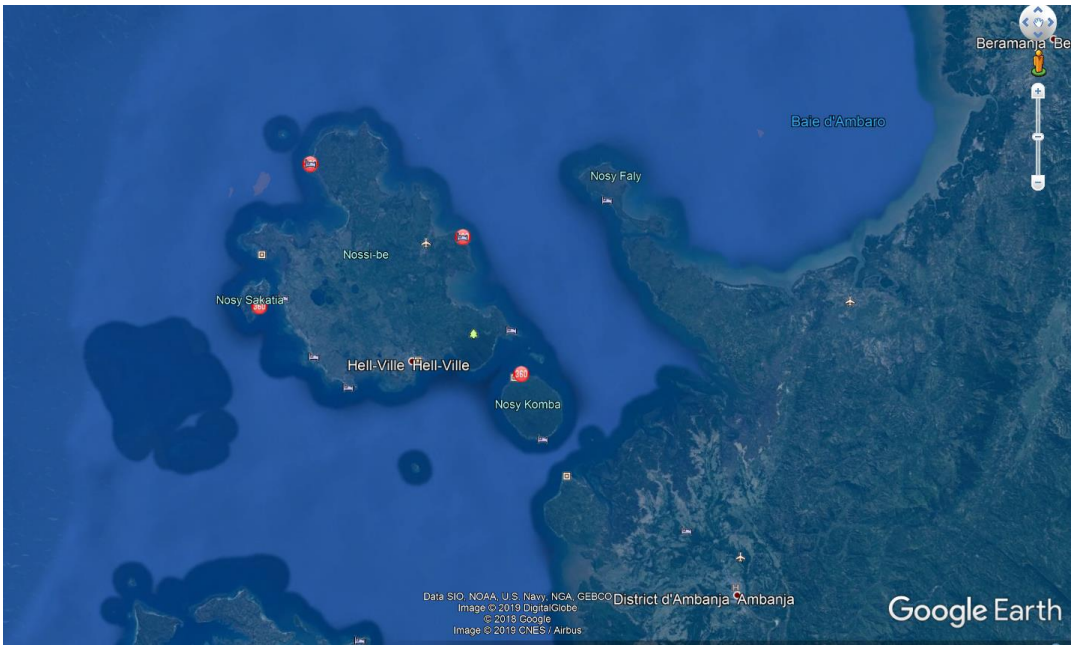
The best ENC is FR374910 which corresponds to the Shom 7491 paper chart at 1 : 350 000

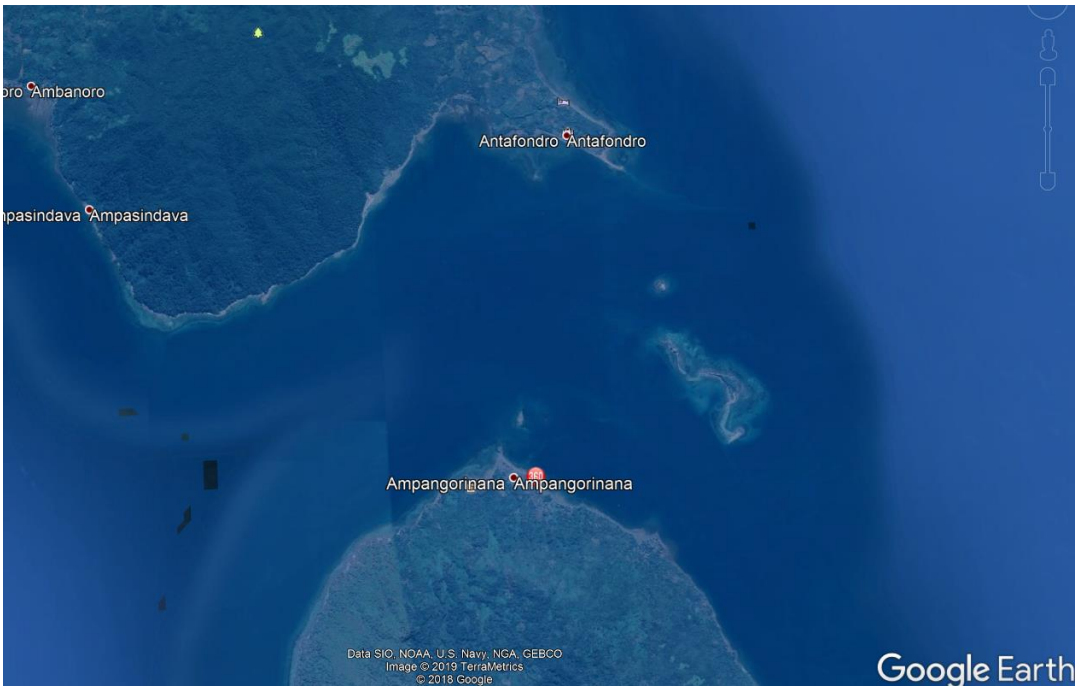




APPENDIX-3: Bing map – Google Earth (2019)

Google Earth (29 June 2019)





Bing Map (29 June 2019)

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