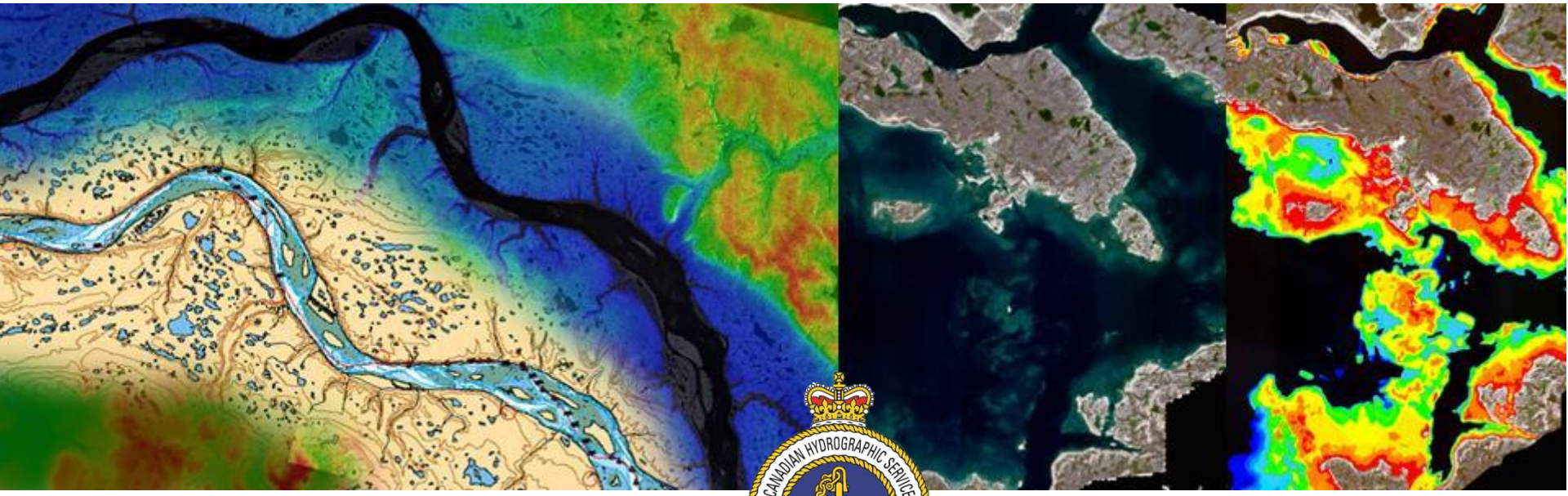
CHS Level of Confidence Approach for SDB

René Chénier, Khalid Omari and Mesha Sagram



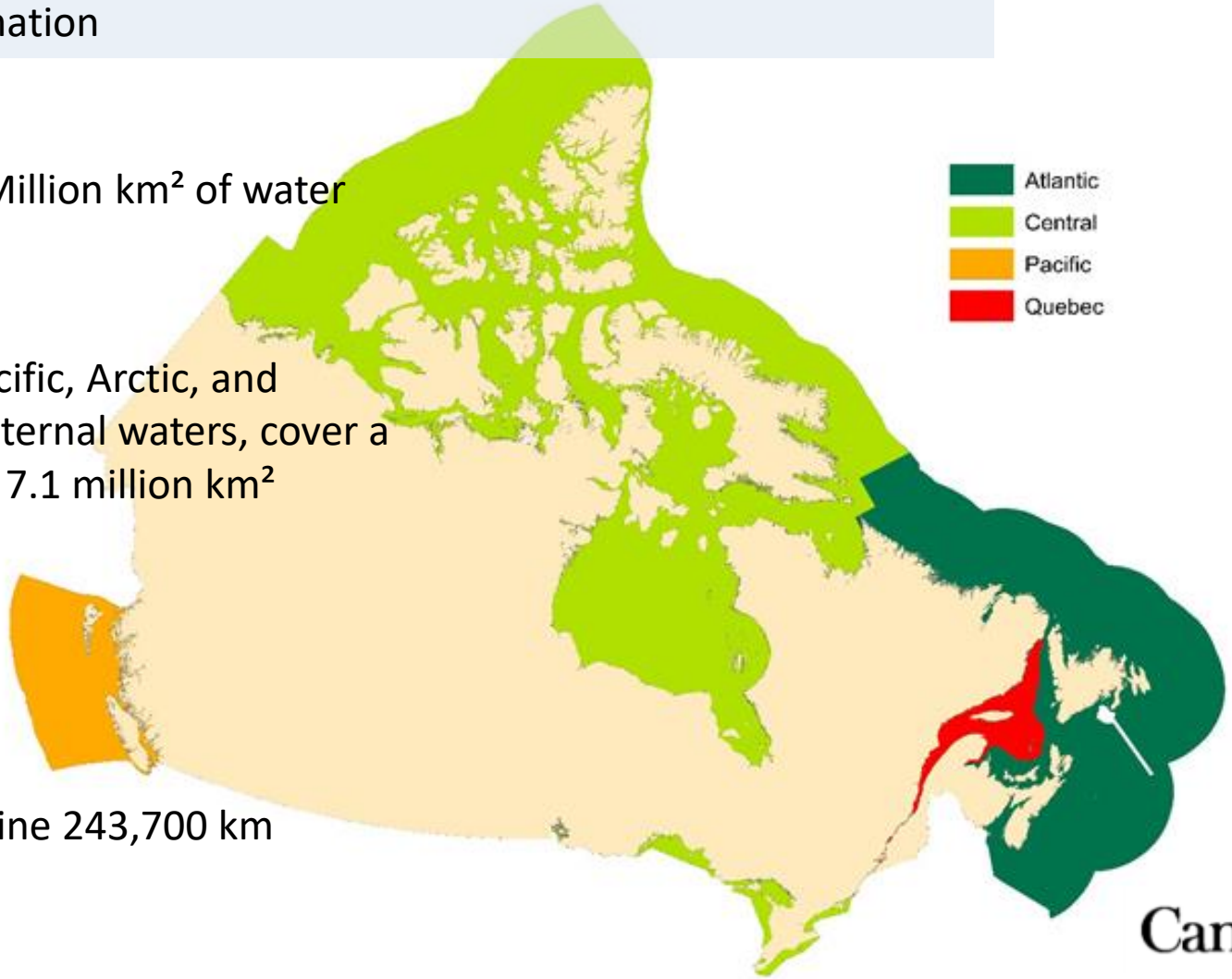
Canadian Hydrographic Service Regions

- CHS is mandated to support safe navigation in Canadian waters
- Responsible for providing up-to-date, authoritative and standardized hydrospatial information

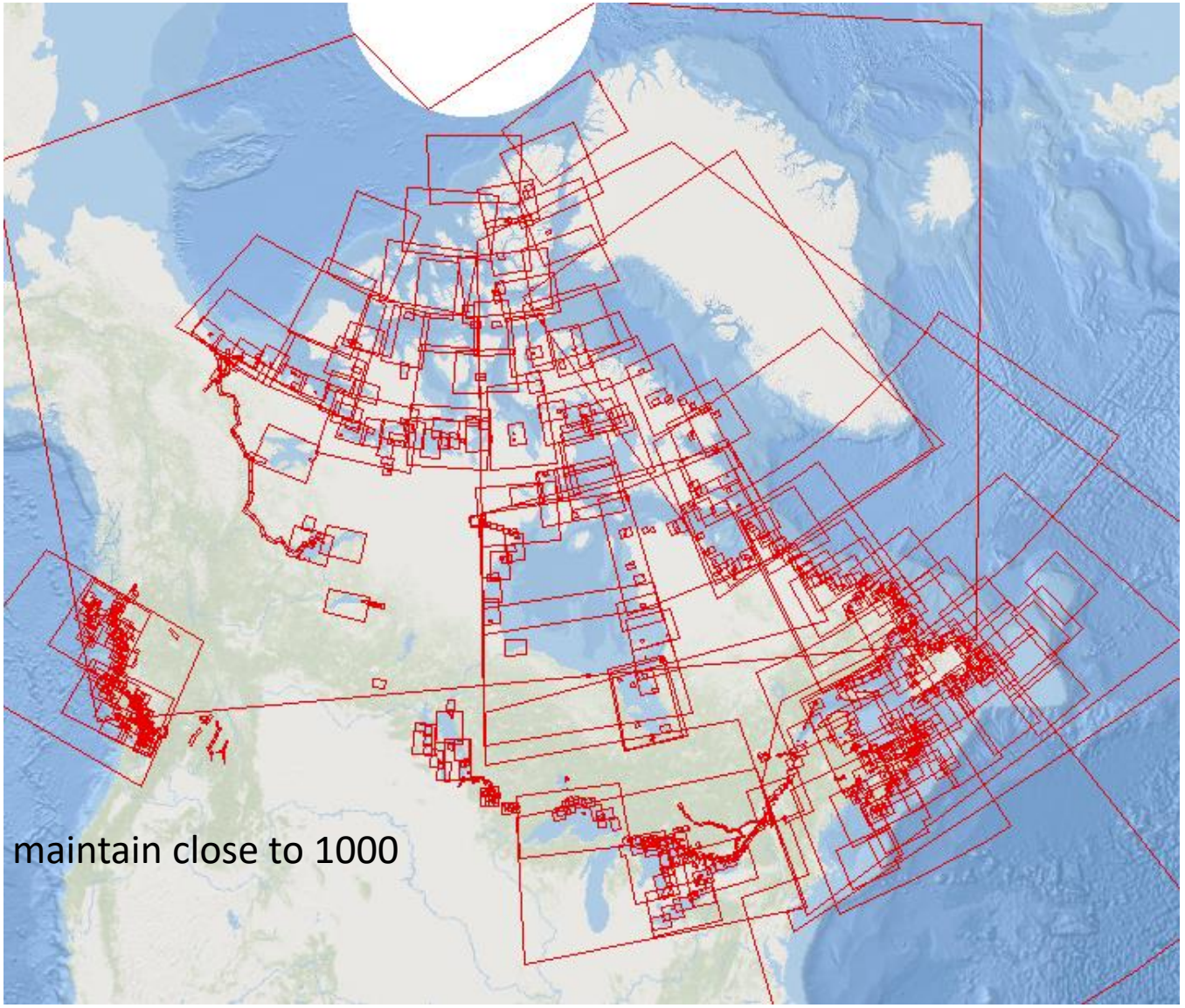
Canadian Arctic : 3.7 Million km² of water

The Oceans (Pacific, Arctic, and Atlantic), and internal waters, cover a surface area of 7.1 million km²

Total coastline 243,700 km



Current Paper Chart Coverage



- Produce and maintain close to 1000 paper charts

Category Zone of Confidence (CATZOC)

Only 14 % of the Arctic is considered as adequately surveyed

CATZOC	Survey Quality	Position Accuracy	Depth Accuracy
A1	Modern	± 5 m + 5% depth	0-10 m: 0.6 m 10-30 m: 0.8 m
A2 & B	Adequate	± 20 m (A2) ± 50 m (B)	0-10 m: 1.2 m 10-30 m: 1.6 m
C	Insufficient	± 500 m	0-10 m: 2.5 m 10-30 m: 3.5 m

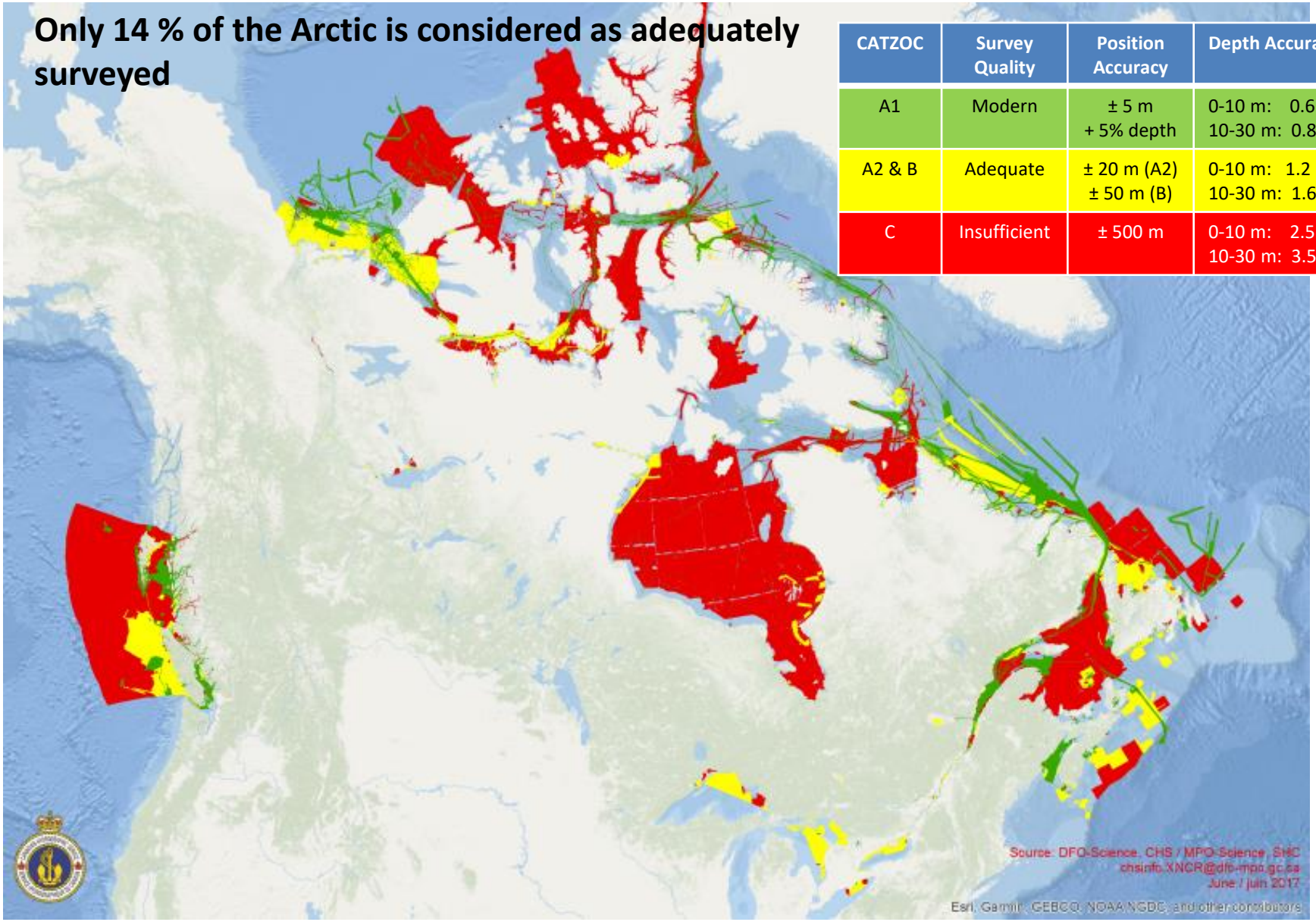


Chart White Space

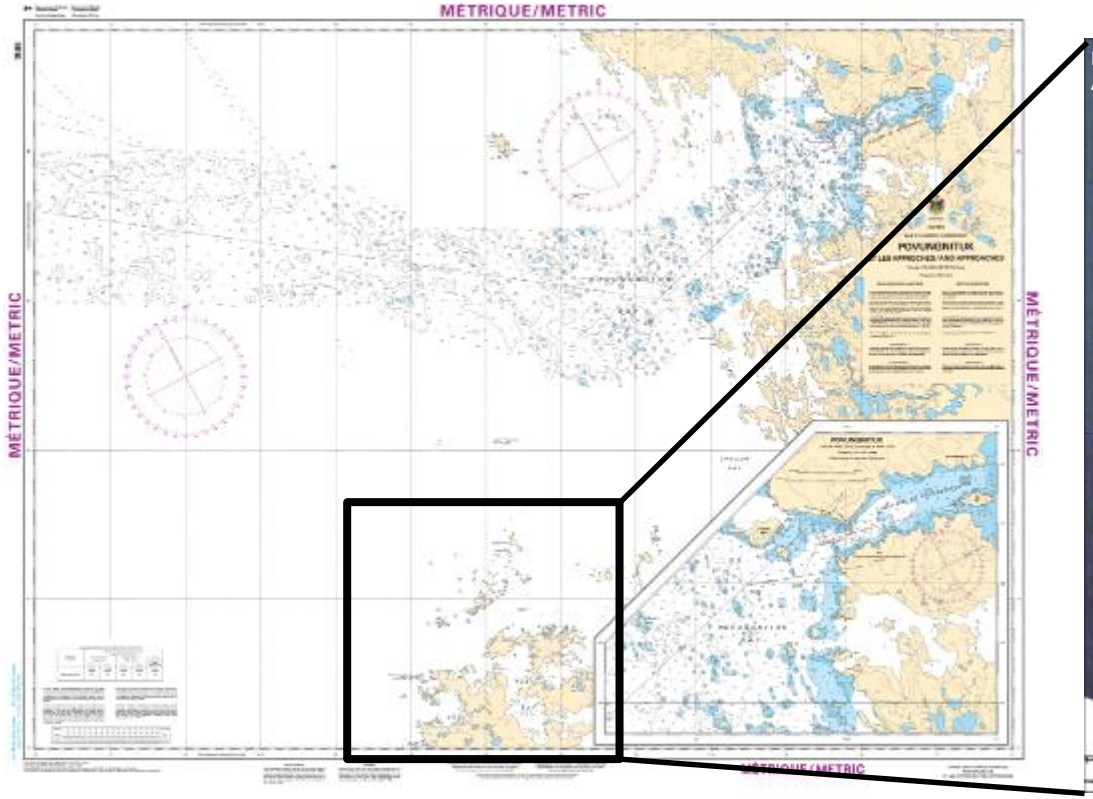


Chart 5510 (Povungnituk, QC). White areas in Chart depicted above are unsurveyed.

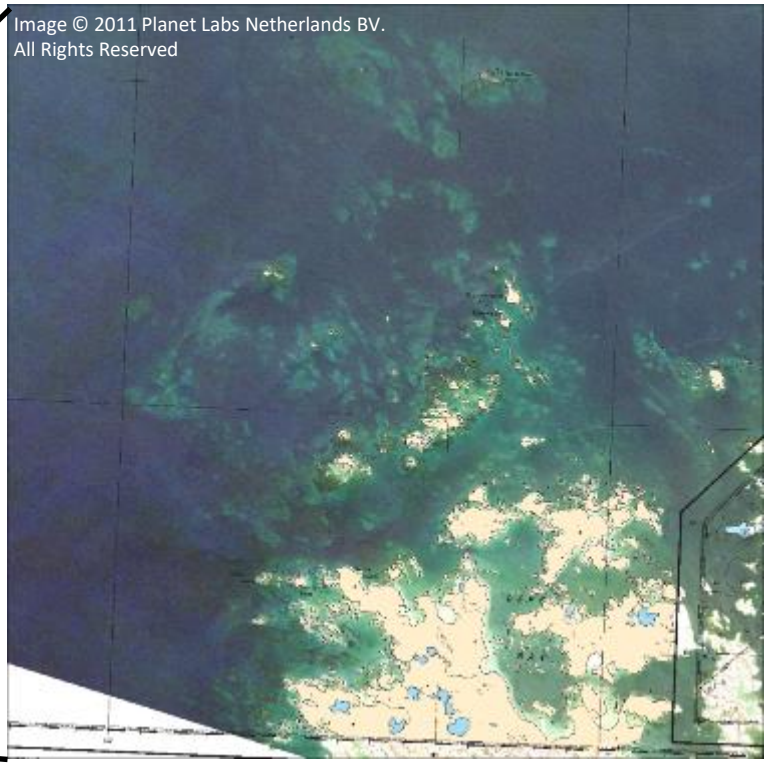
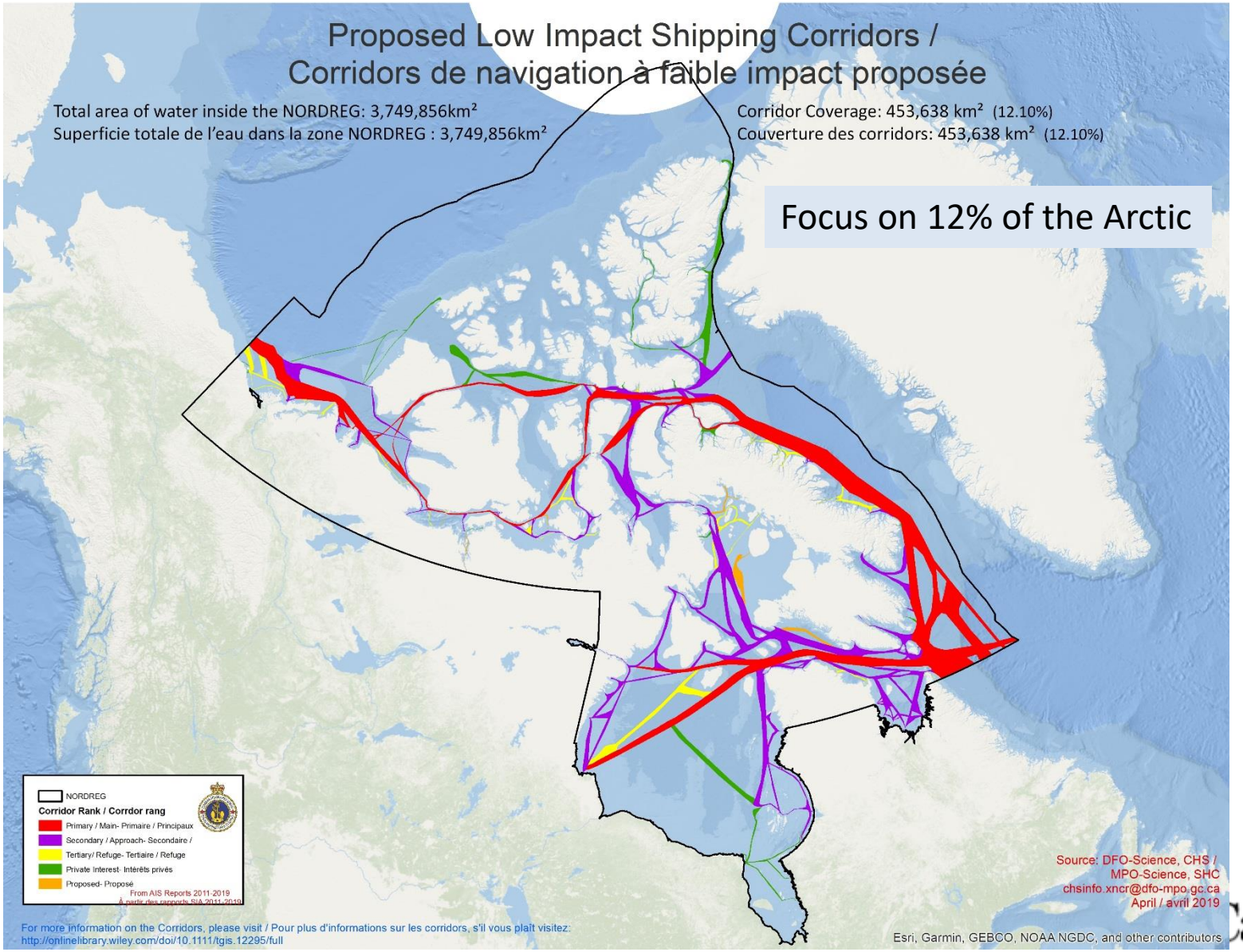


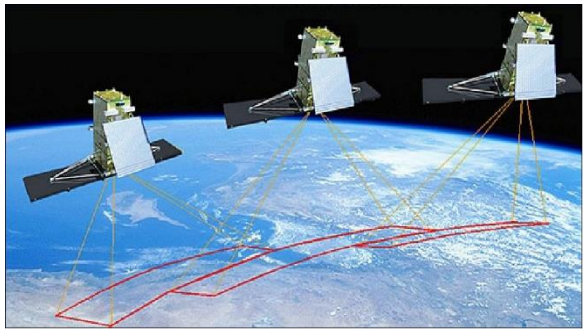
Chart 5510 overlaid on RapidEye image (July 12, 2011).

Proposed Low Impact Shipping Corridors



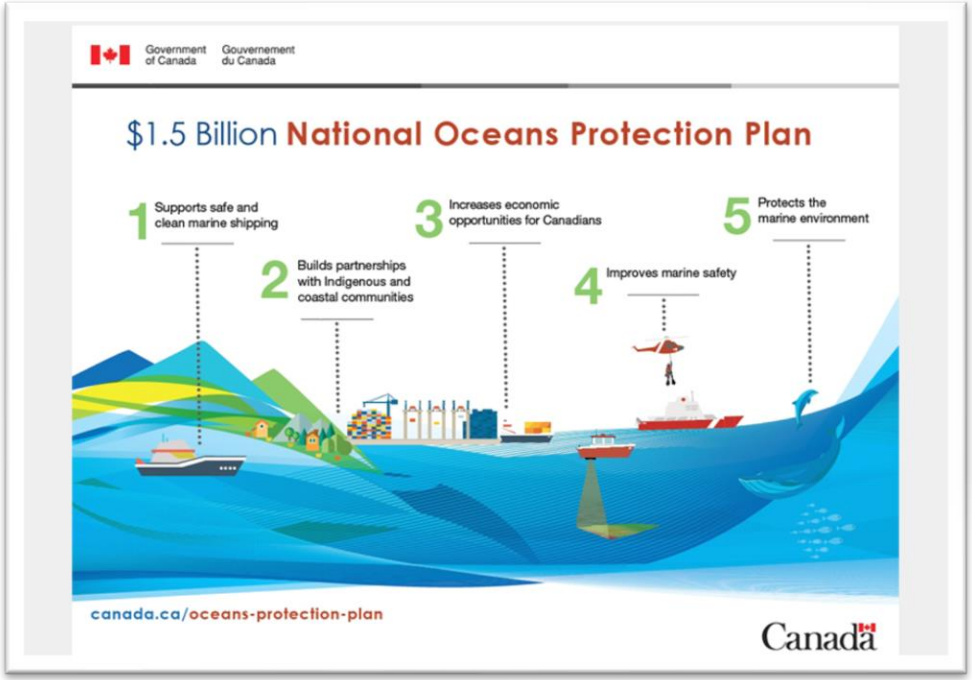
Canadian Space Agency (CSA) Funding

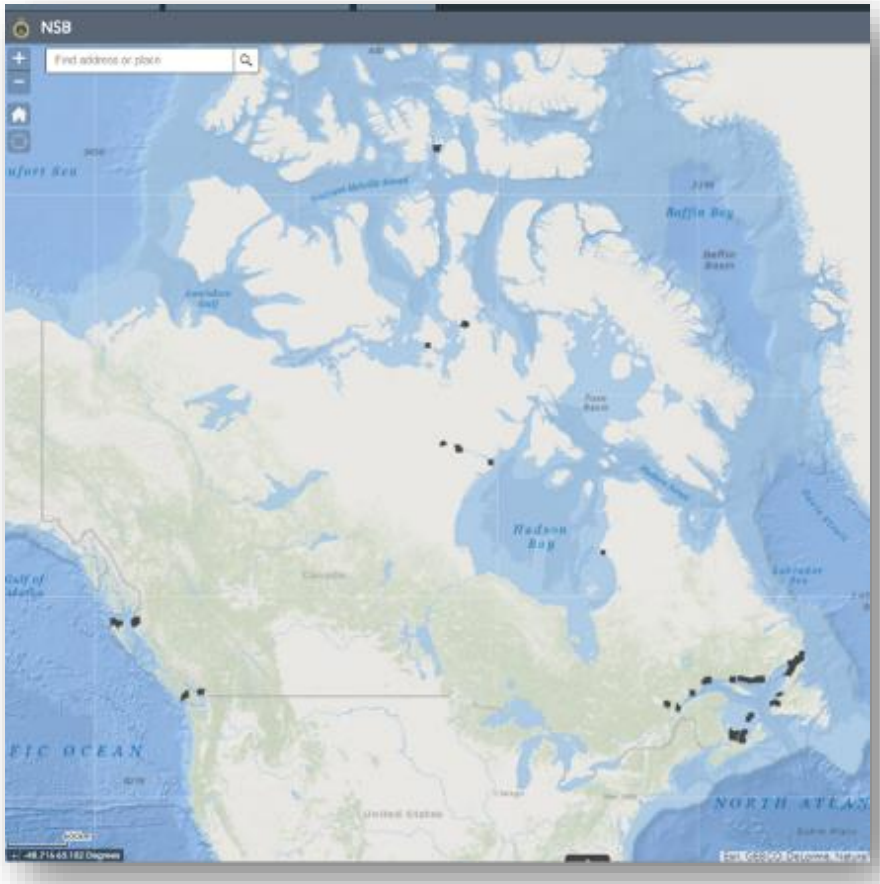
- **Government Related Initiatives Program (GRIP)**
  - Extraction of accurate Coastline and Intertidal Zones
  - **Satellite Derived Bathymetry (SDB)**
  - Change Detection
  - Shipping Corridor Determination
  - Data Integration in CHS Processes and Products
- **Data Utilization and Application Plan (DUAP)**
  - RCM Data Simulation
  - Shorelines, Intertidal Zones and Tidal Height
  - Charting and Surveying Priorities
  - Synthetic Aperture Radar (SAR) Bathymetry



Oceans Protection Plan

- Multibeam and LiDAR surveys for priority and high risk areas across Canada
- Support for remote sensing projects

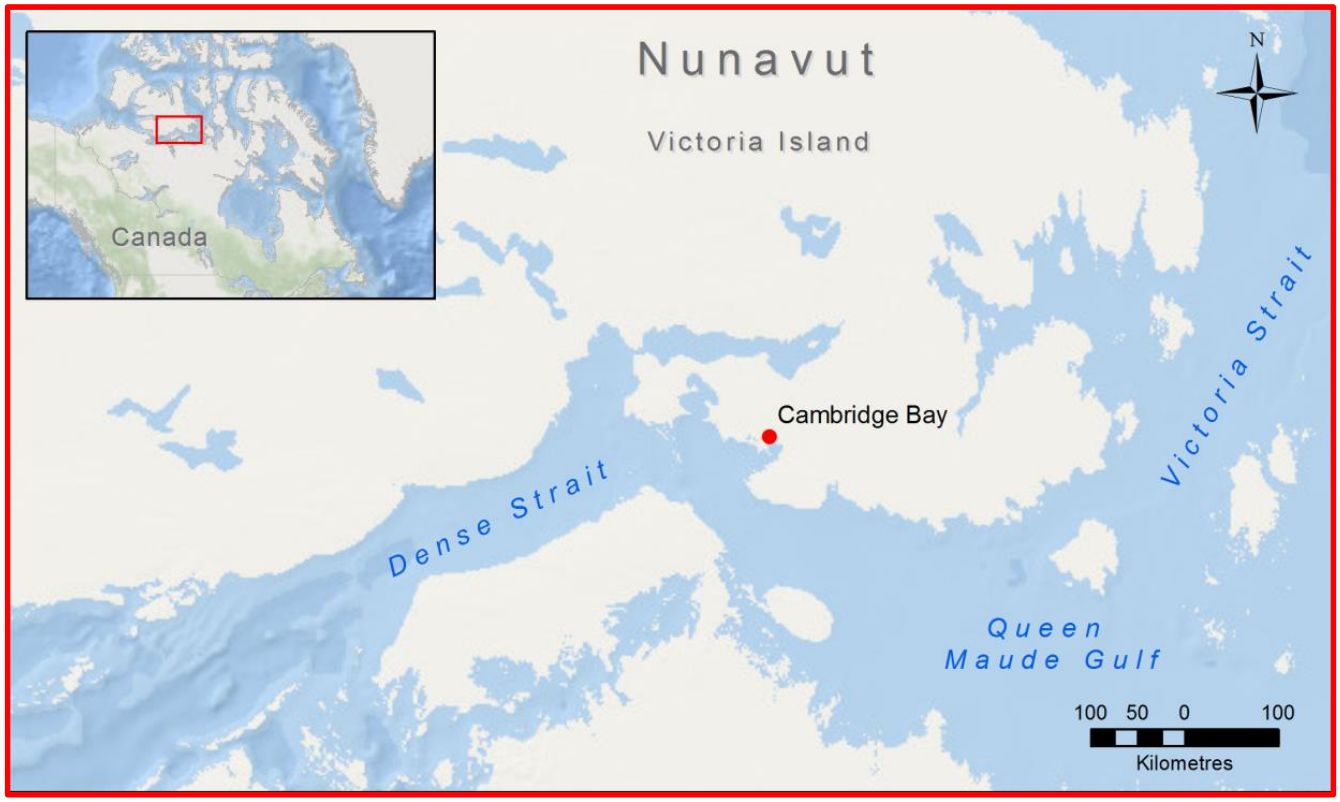




Canada

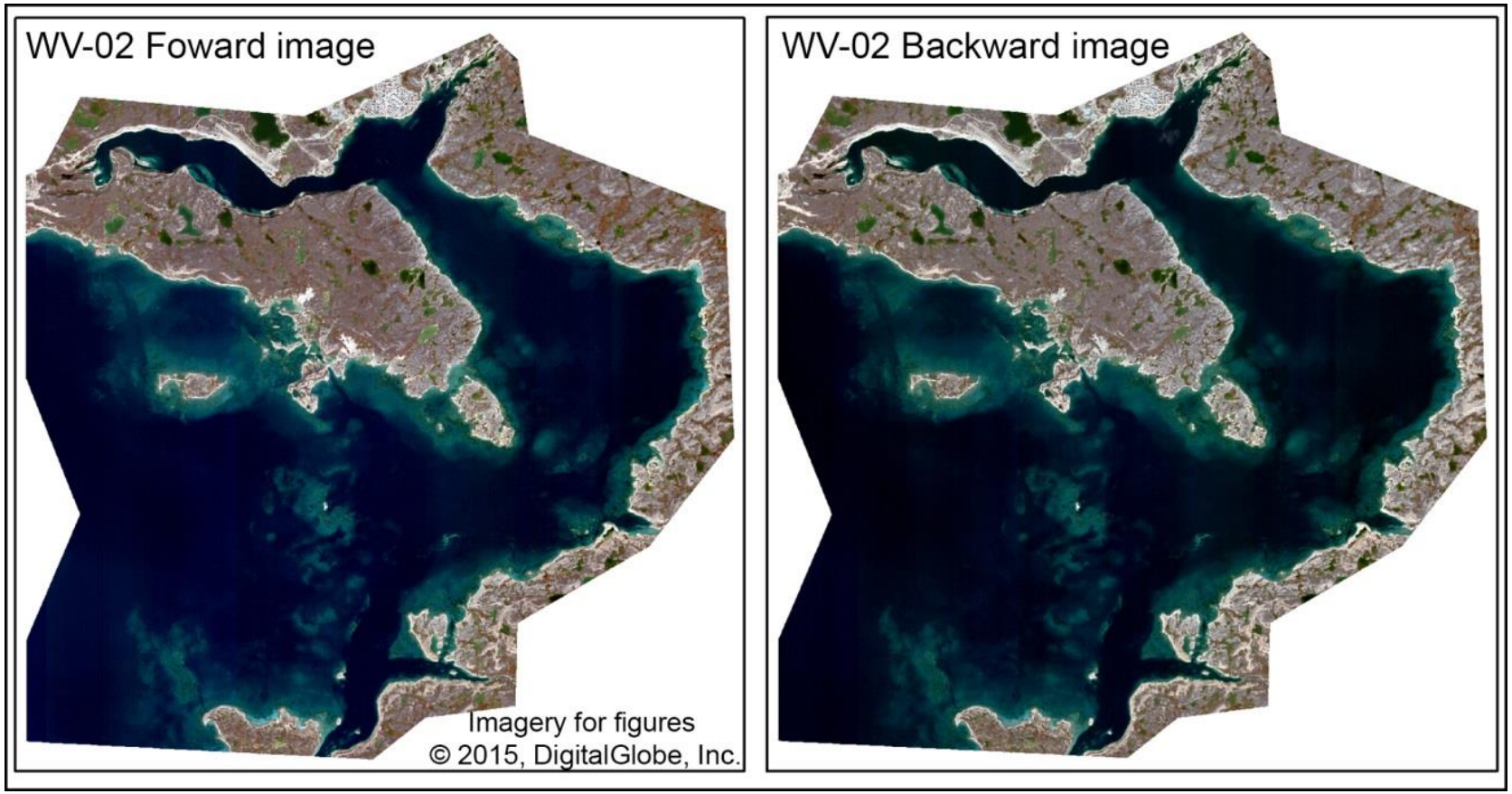
Study Site -Cambridge Bay

- The Canadian Arctic is where CHS has the most gaps in hydrographic surveys
- The study site is located in Cambridge Bay, Nunavut (69°07' N, 105°02' W)
- Cambridge Bay is a hamlet situated on Victoria Island

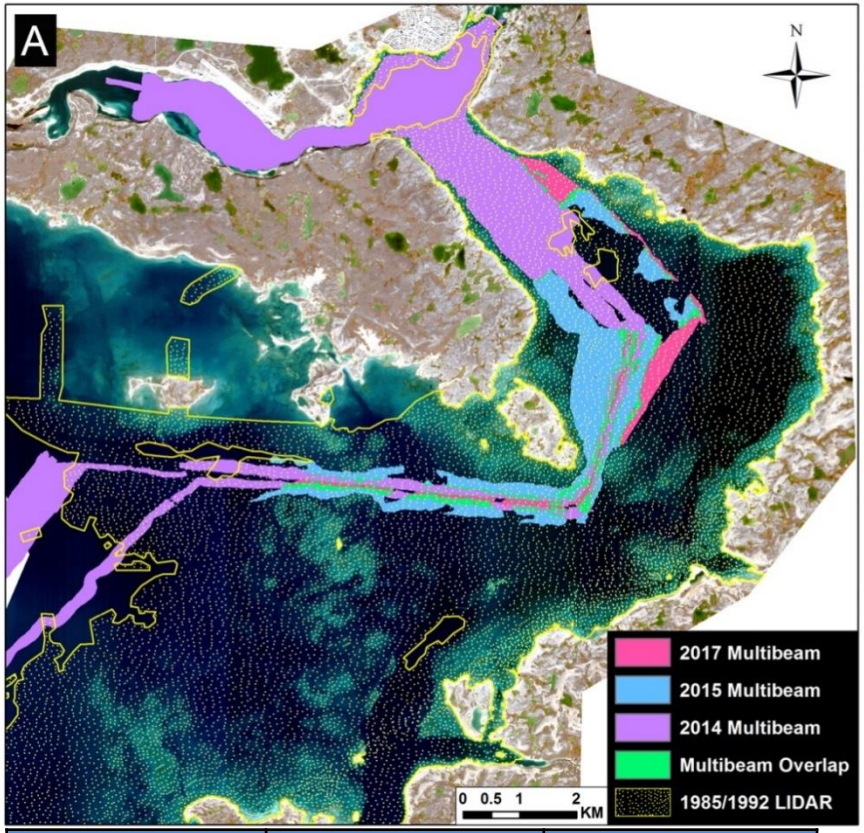


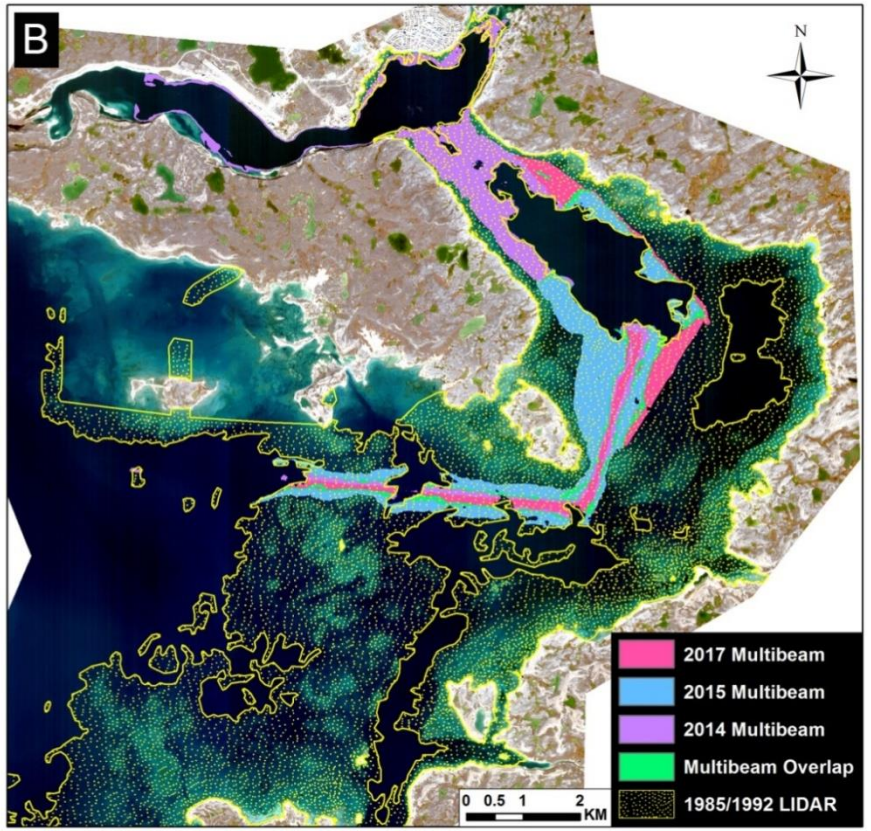
Dataset: Wordview-2 Stereo Pair

WorldView-2 stereo pair acquired on September 20, 2015 over Cambridge Bay



Survey Data (MultiBeam / LiDAR)





Survey Type	Year	Number of points (0-20 m)
Multibeam	2017	599,305
Multibeam	2015	1,265,263
Multibeam	2014	1,284,582
LiDAR	1992	1193
LiDAR	1985	8953
	Total	3,159,297

A- All survey points

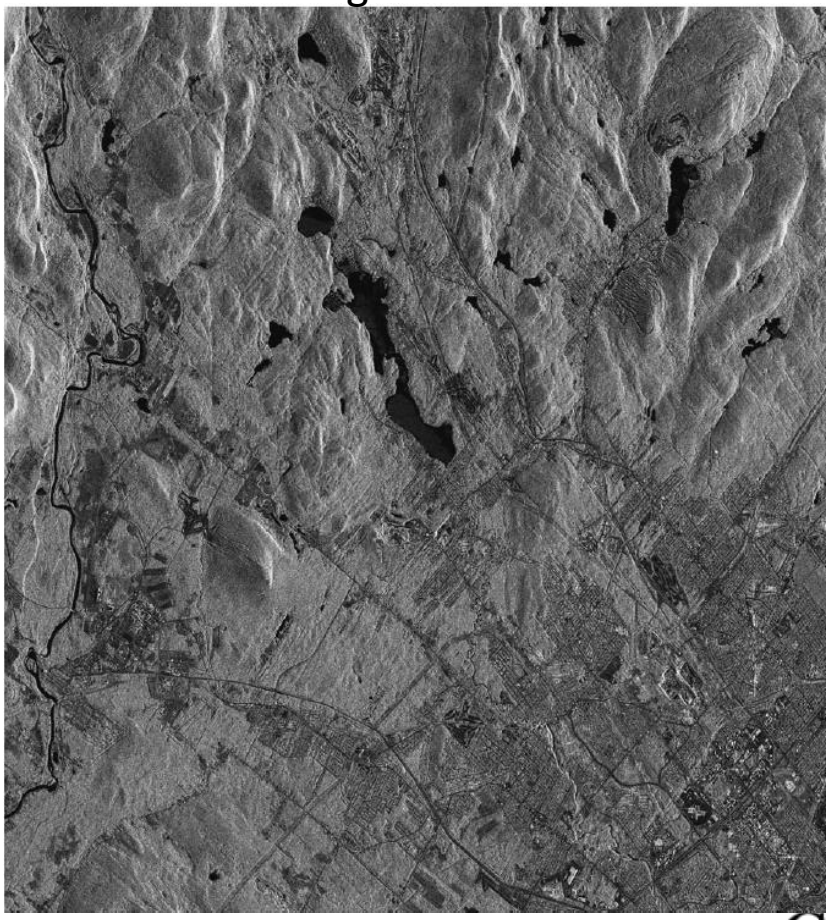
B- Survey points from 0-20 m

Geometric Processing- Physical model

Mode	GCP	ICP	ICP RMS errors (m) X, Y,
U2	8	81	1.5, 1.4
U25	8	105	1.4, 1.5

- **The accuracy of the Radarsat orbit**: MDA guarantees 5 m with 90 % level of confidence.

The elevation ranges from 10 m to 1000 m



SDB Approaches Evaluated

- Photogrammetric 3D manual approach
  - Digital photogrammetric software SOCET SET
- Photogrammetric Automatic approach
  - PCI Geomatica -*Semi-Global Matching* (SGM) algorithm
- Empirical approach
  - Multi-band approach
- Classification
  - Random forest

Approaches Evaluated

Classification :

- A random forest decision tree classification was used
- Training areas were collected using the survey information
- Classes of depth of 0.5 m intervals were created using available survey points
- The random forest classification was applied to the multispectral bands (**Red, Green, Blue, and Yellow)**

Empirical - multi-band model (Lyzenga 1985)

- A Multi-band approach was selected , the multispectral bands used **(Red, Green, Blue, and Yellow)**
- 10% of the survey data were used for the creation of the model

Approaches Evaluated

Photogrammetric approach:

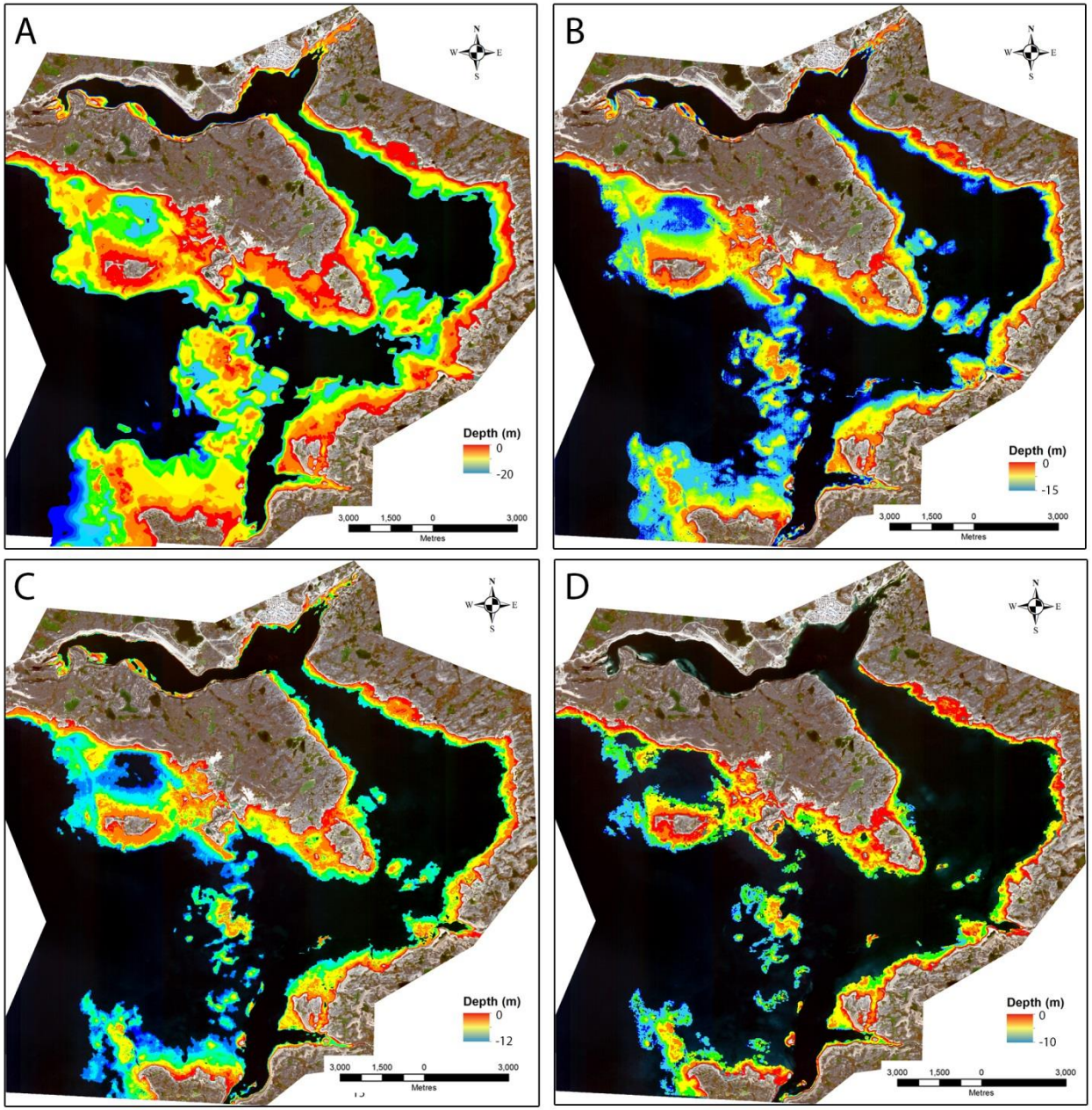
- Geometric model was computed using the Rational Polynomial Coefficients (RPCs)
- Additional tie points (~1000) were collected in order to obtain better relative accuracy between the images

Photogrammetry 3D Manual approach :

- Photogrammetrist visually extracted the isobaths at 1 m interval
- Light and tidal correction were done with survey points as a reference to determine the appropriate water depth

Photogrammetry Automatic approach:

- PCI Geomatics -Semi-Global Matching (SGM) algorithm
- Light refraction and tidal correction was applied



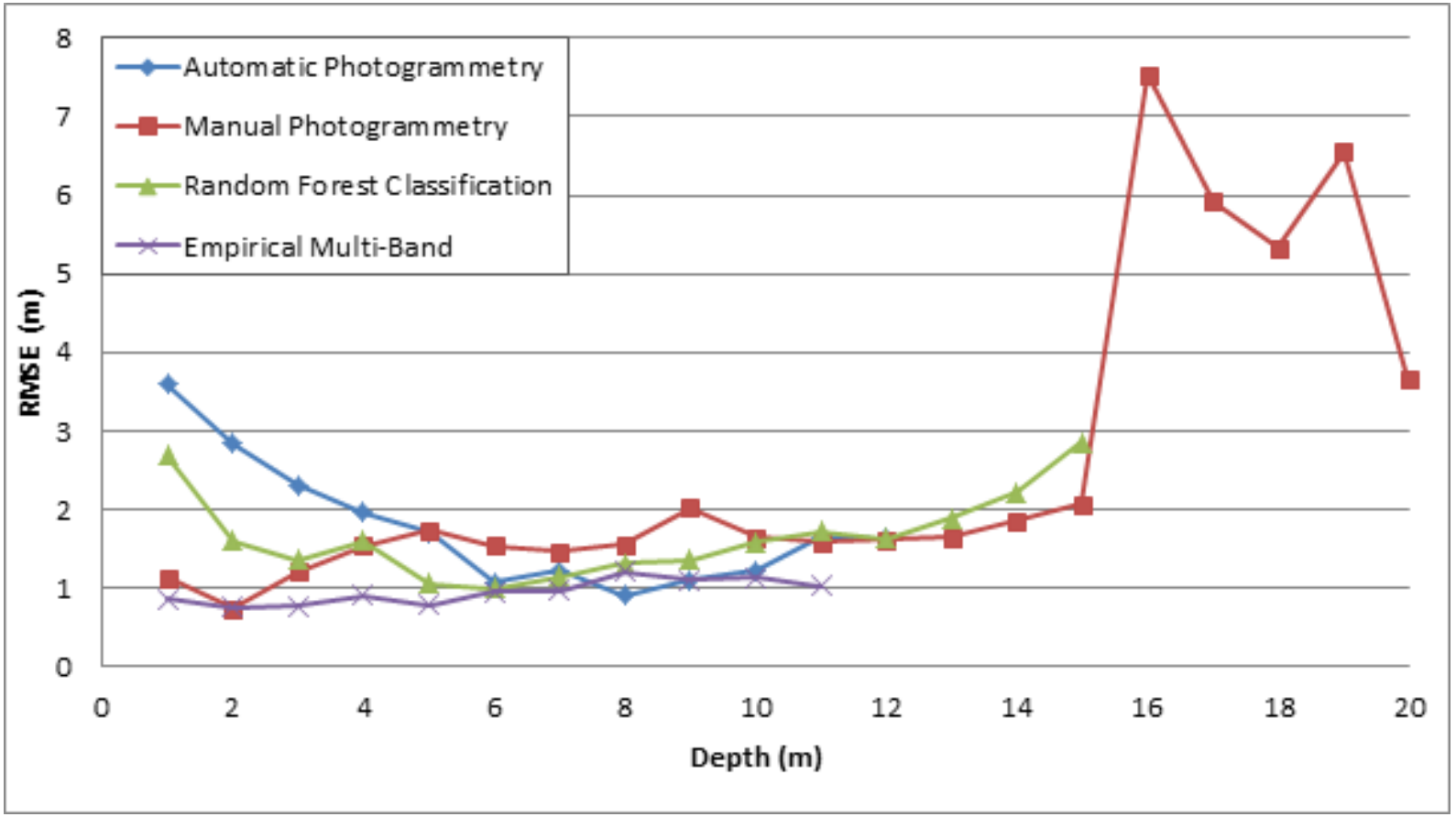
Results

For total extracted coverage

Approach	Coverage 0-20 m
A- 3D Manual Photogrammetry	100 %
B- Classification Random Forest	81 %
C- Empirical Multiband	59 %
D- Automatic Photogrammetry	39 %

Results – Total Coverage

The 3D Photogrammetric and Classification approaches accurately extracted depths up to 15 m



The International Hydrographic Organization (IHO) S-57 Standard

CATZOC Level	Depth Range (m)	Required Accuracy (± m)
A1	0-10	0.6
	10-30	0.8
A2 & B	0-10	1.2
	10-30	1.6
C	0-10	2.5
	10-30	3.5

Accuracy Assessment for individual SDB techniques

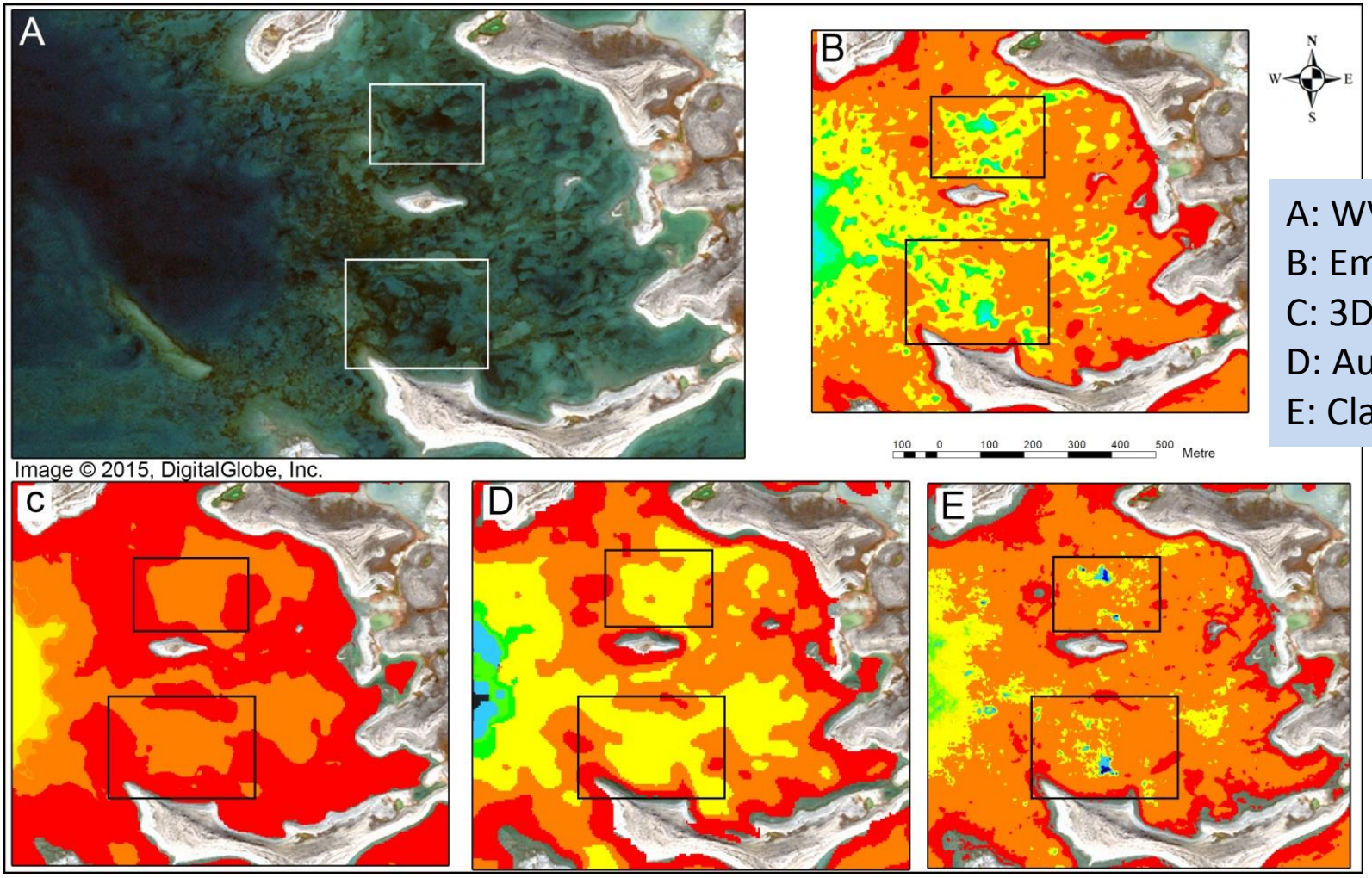
Results for individual SDB techniques in the **common coverage** area

SDB Method	LE90 (m) Depth Range							
	Bias (0–10 m)	0–10	0–2	2–4	4–6	6–8	8–10	10–14
Empirical	-0.20	0.95	1.51	1.14	0.75	1.02	0.93	1.46
Manual Photogrammetry	-0.58	1.58	1.51	1.68	1.35	1.38	1.19	1.76
Automatic Photogrammetry	0.75	1.54	0.46	0.65	1.45	1.55	**1.88**	2.10
Random Forest	-0.38	1.67	0.48	0.54	1.08	1.73	**2.28**	2.76
Number of Points	38,773		765	2128	13,511	18,168	4201	359

Empirical approach very close to meet the CATZOC A2 & B , 1.2 m

Dark Features (Benthic Environment)

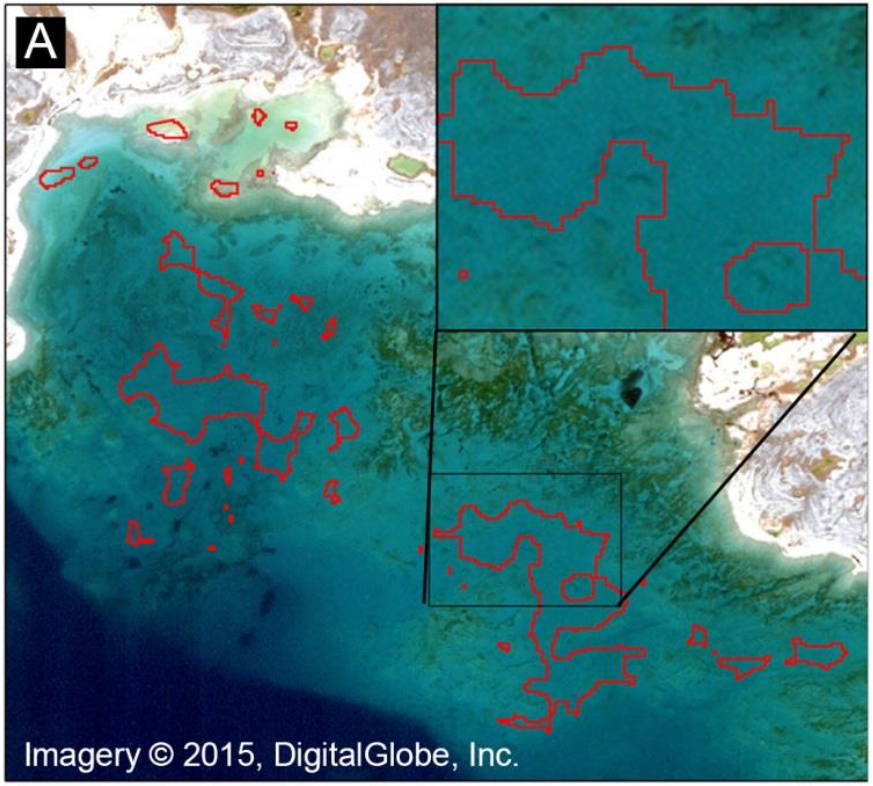
Dark features, commonly caused by underwater vegetation, are of particular concern for the empirical approach as it confuses dark features with deep water

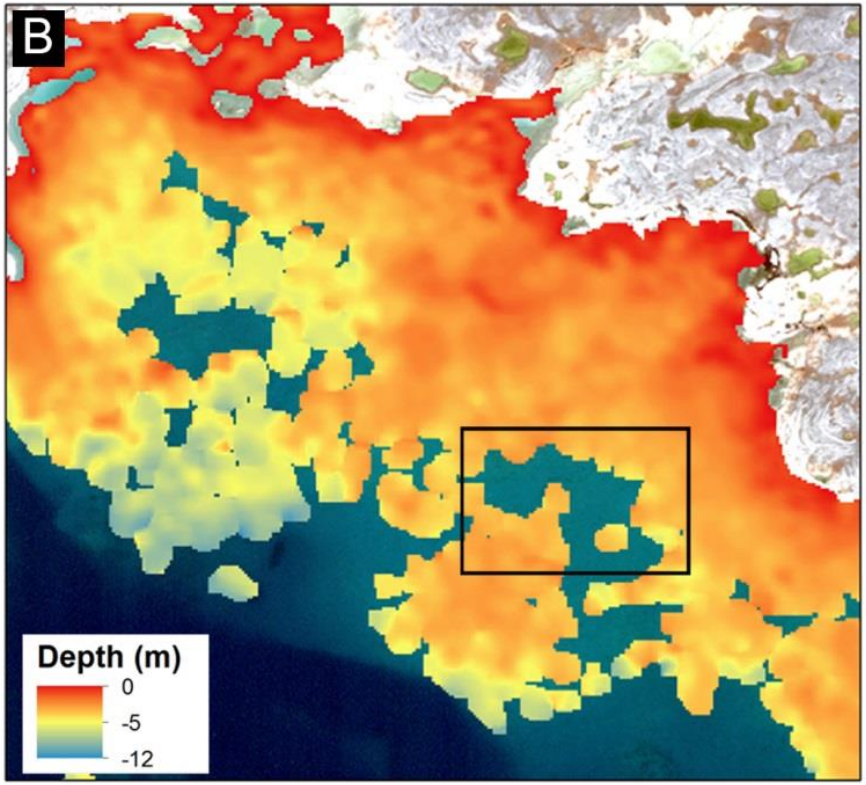


A: WV-02 image
B: Empirical
C: 3D stereo
D: Automatic Stereo
E: Classification

Homogeneous Bottom Types

Homogenous areas : For the **Photogrammetric Automatic approach,** within homogeneous areas **like sand,** the algorithm encounters difficulties with matching pixels, preventing a correlation from being achieved





Level of Confidence Approach

- The percentage of the overlap area captured by four, three and two agreeing techniques that agree within 1 m
- **81 % of the total common coverage** agreed with at least **3 techniques**

Number of Techniques Agreeing within 1 m	Approaches within Combination[1]	Overall Combination RMSE (m) (0–10 m)	Rank	% Coverage of Overlap Area[2]
4	AP, EM, MP, RF	0.61	1	31
3	AP, EM, RF	0.60	2	50
	AP, MP, RF	0.64	3	
	AP, EM, MP	0.69	4	
	EM, MP, RF	0.80	5	
2	AP, EM	0.63	6	19
	AP, RF	0.70	7	
	AP, MP	0.71	8	
	EM, MP	0.82	9	
	EM, RF	0.83	10	
	MP, RF	0.90	11	

Results of Level of Confidence Approach

Number of Techniques Agreeing within 1 m			LE90 (m)						
			Depth Range						
	Coverage %	Bias	0–10	0–2	2–4	4–6	6–8	8–10	10–14
4	31	-0.10	1.01	1.21	0.85	0.85	0.98	1.27	1.00
3	50	-0.19	1.26	1.23	0.90	1.14	1.28	1.25	1.24
2	19	0.05	1.28	1.30	1.21	1.25	1.24	1.07	1.90
4 and 3	81	-0.16	1.21	1.26	0.87	1.08	1.24	1.28	1.20
All	100	-0.12	1.24	1.30	0.95	1.15	1.24	1.18	1.78

Individual approaches

SDB Method	LE90 (m) Depth Range							
	Bias	0–10	0–2	2–4	4–6	6–8	8–10	10–14
Empirical	-0.20	0.95	1.51	1.14	0.75	1.02	0.93	1.46
Manual Photogrammetry	-0.58	1.58	1.51	1.68	1.35	1.38	1.19	1.76
Automatic Photogrammetry	0.75	1.54	0.46	0.65	1.45	1.55	1.88	2.10
Random Forest	-0.38	1.67	0.48	0.54	1.08	1.73	2.28	2.76

Bias was reduced

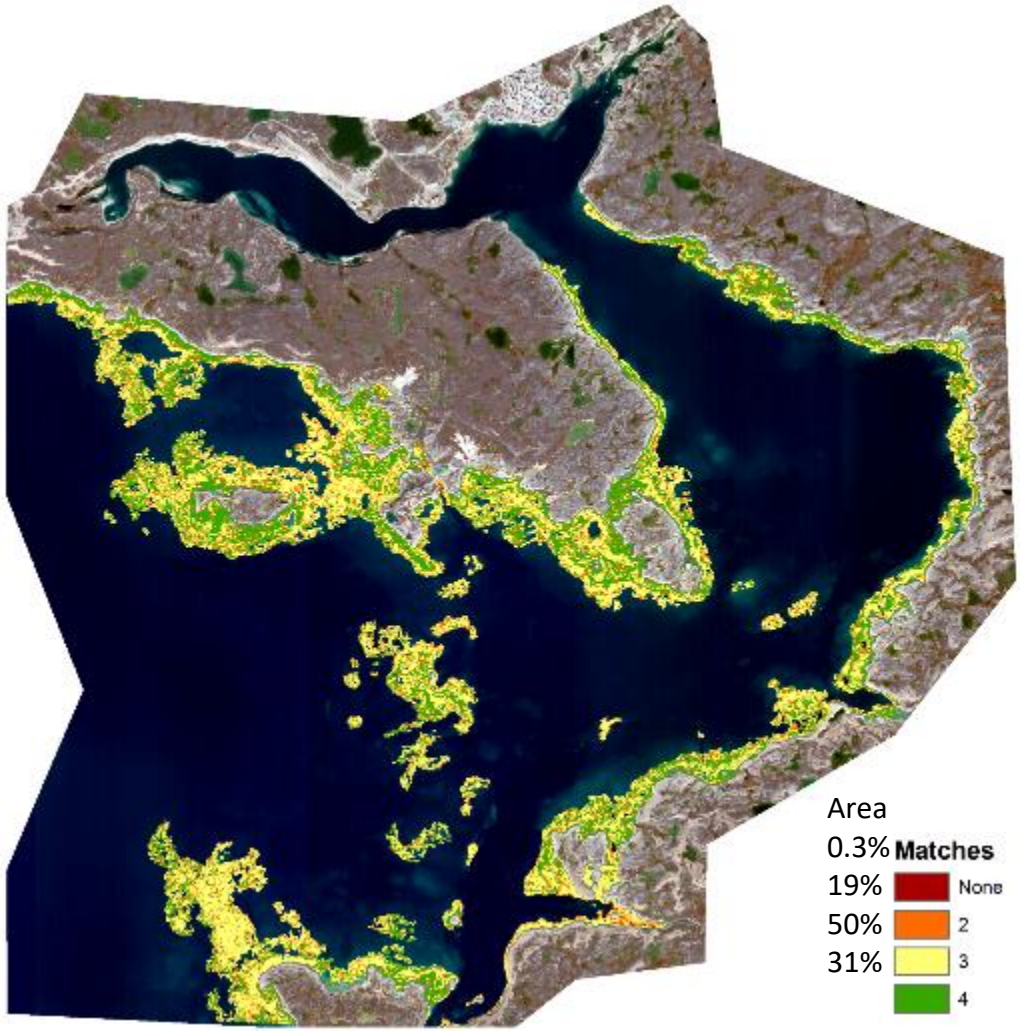
CATZOC B until 14 m for 81 % of the total coverage

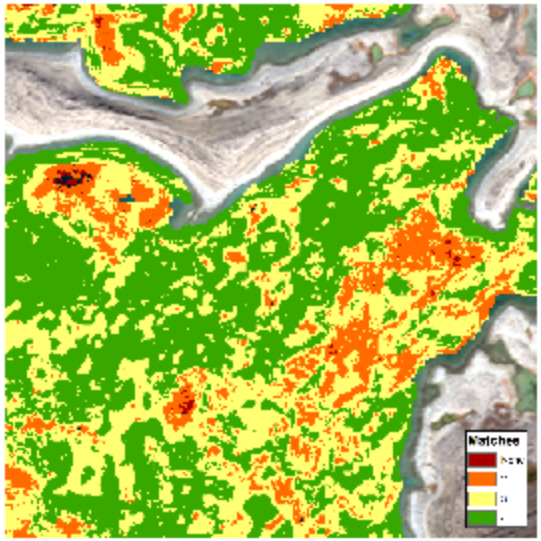
Level of confidence approach

Number of Techniques Agreeing within 1 m			LE90 (m) Depth Range						
	Coverage %	Bias	0–10	0–2	2–4	4–6	6–8	8–10	10–14
4	31	-0.10	1.01	1.21	0.85	0.85	0.98	1.27	1.00
3	50	-0.19	1.26	1.23	0.90	1.14	1.28	1.25	1.24
2	19	0.05	1.28	1.30	1.21	1.25	1.24	1.07	1.90
4 and 3	81	-0.16	1.21	1.26	0.87	1.08	1.24	1.28	**1.20**
All	100	-0.12	1.24	1.30	0.95	1.15	1.24	1.18	1.78

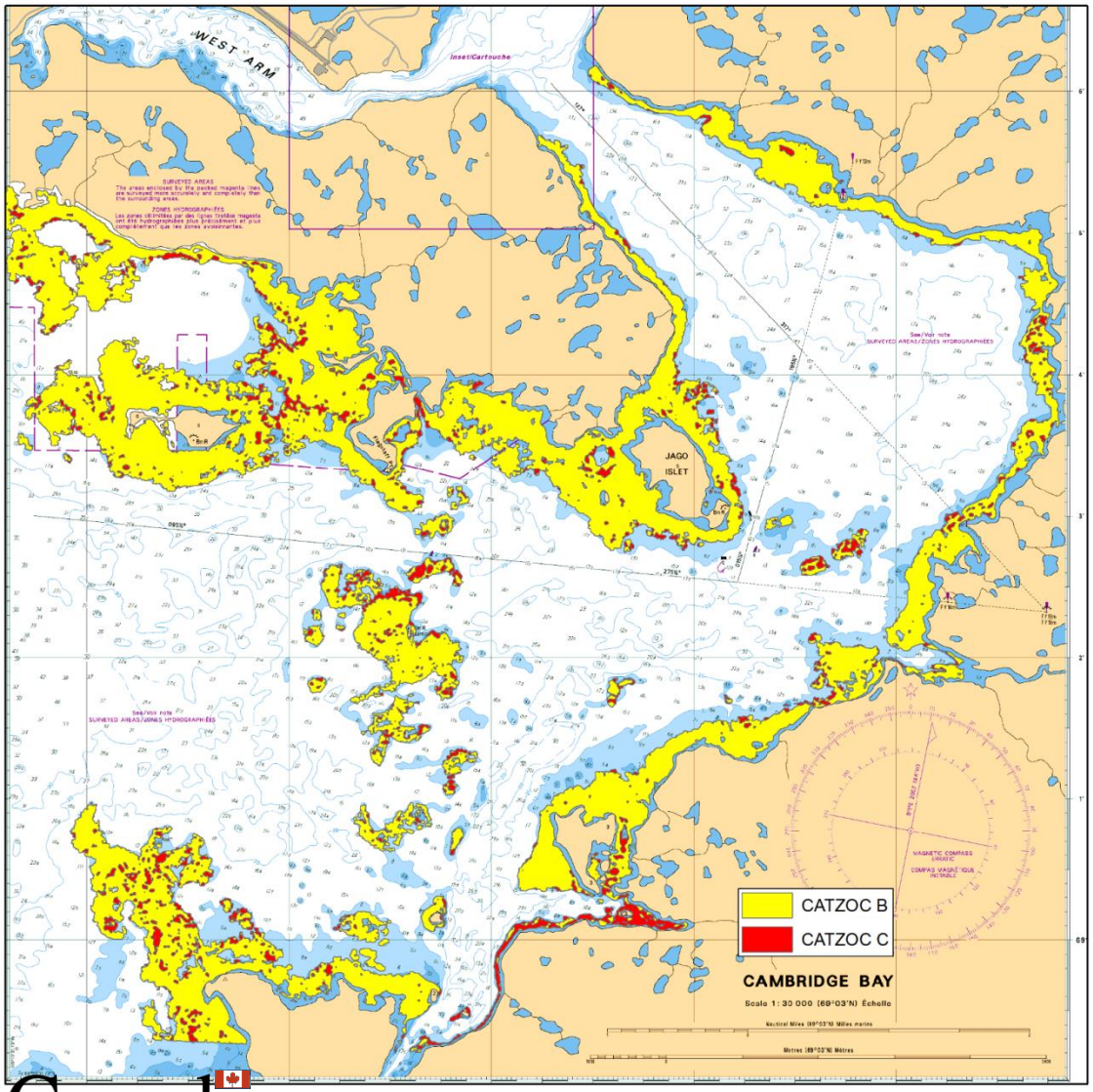
SDB Confidence Level masks

Creation of a mask can be used for the QC





Source Classification Diagram



CHS released its first chart (4955) with mention of SDB as a source

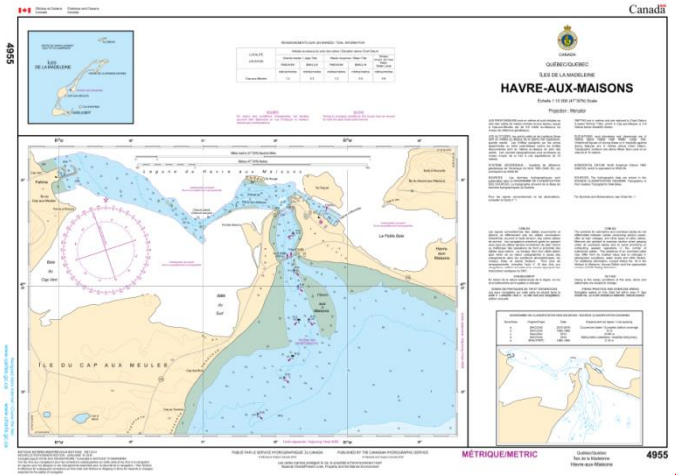
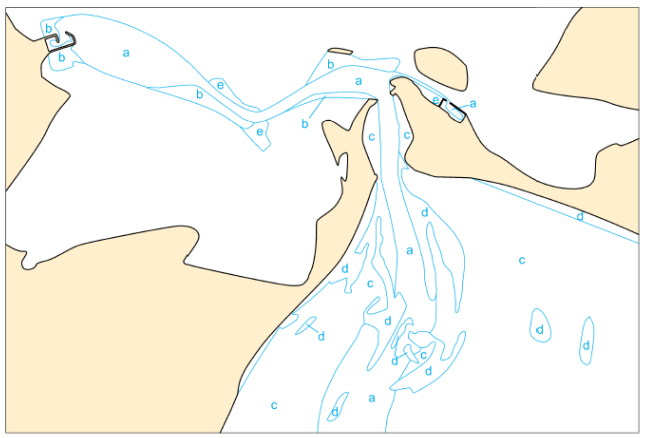
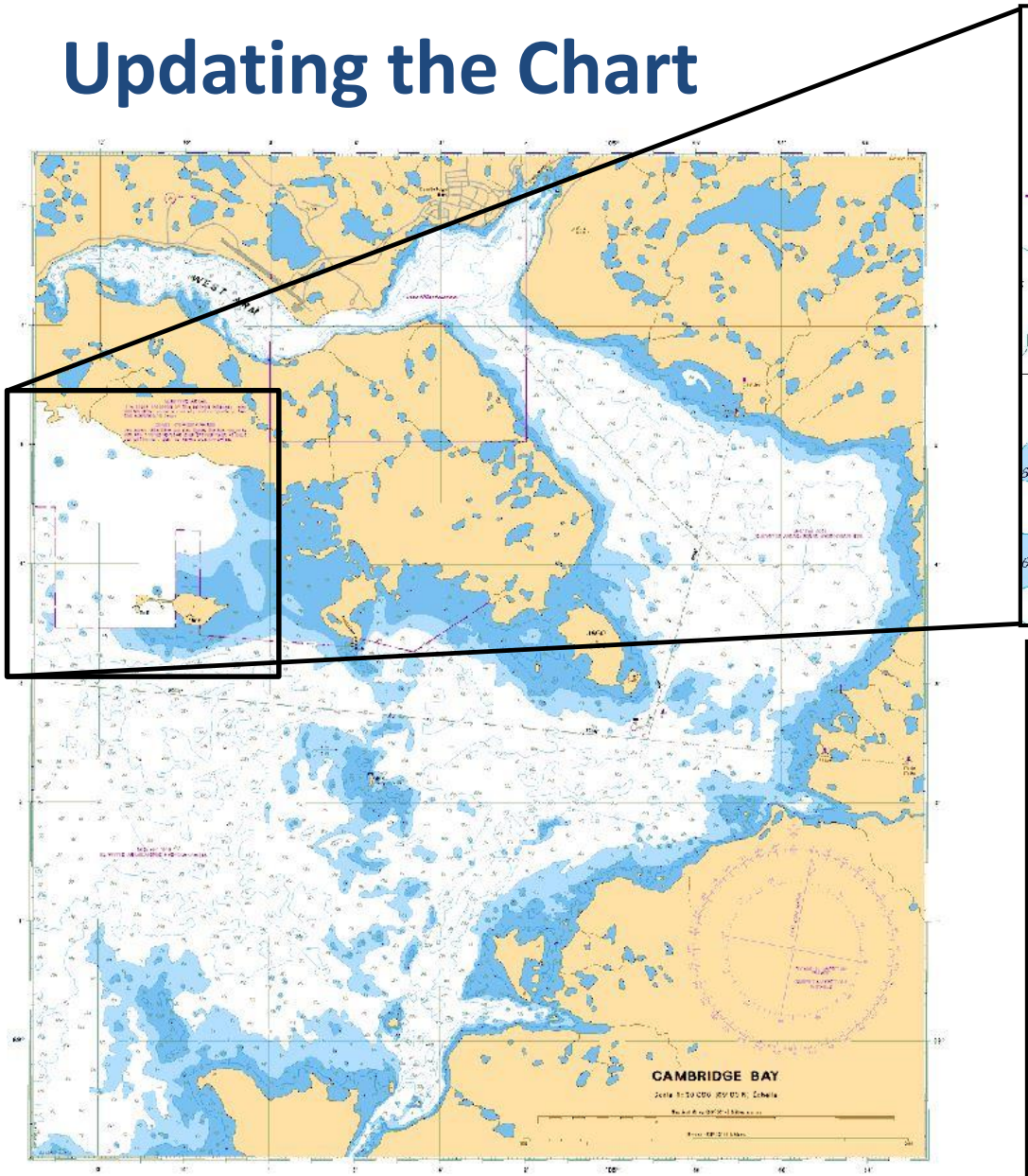


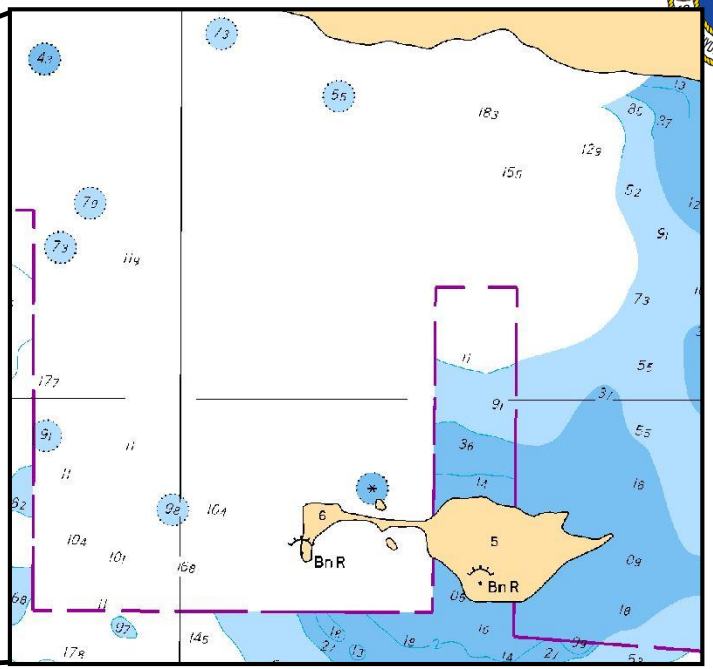
DIAGRAMME DE CLASSIFICATION DES SOURCES / SOURCE CLASSIFICATION DIAGRAM

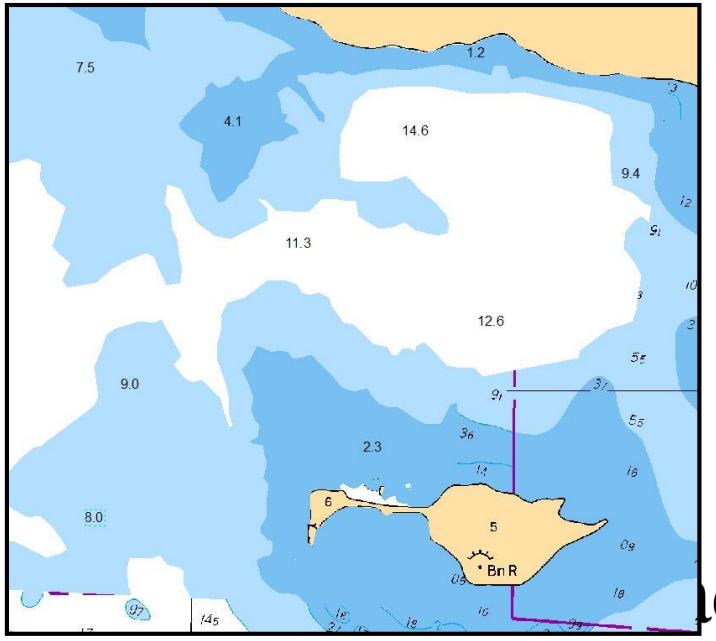
Zone/Area	Origine/Origin	Date	Espacement de lignes / Line spacing
a	SHC/CHS	2013-2016	Couverture totale / Complete bottom coverage
b	SHC/CHS	1983-1986	10 m
c	Gouv/Gov	2014	10-60 m
d	SHC/CHS	2016	Bathymétrie satellitaire / Satellite bathymetry
e	SPAC/PSPC	1985-1990	5-10 m



Updating the Chart







Conclusion

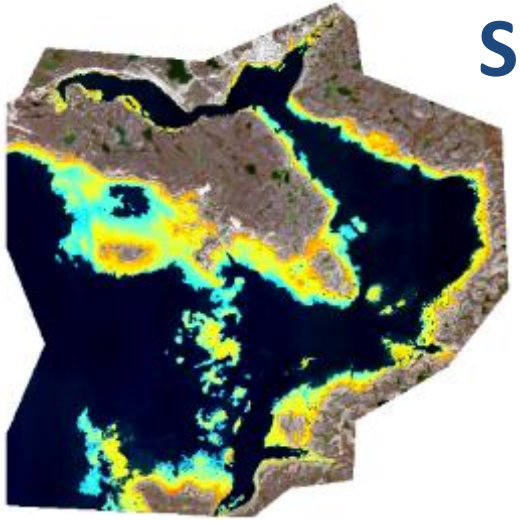
- **The 3D manual photogrammetric** extraction was the approach that provided the most SDB coverage but is more **time intensive** and costly
- **The empirical** approach provided the **best overall accuracy** but is **sensitive to dark features**
- **The photogrammetric automatic** approach is **not affected by dark features** but its **coverage is limited**
- **The classification** provided good results until 15 m of water depth and is **less sensitive to dark feature** than the empirical approach

For CHS, the best approach would be a hybrid approach that would use the advantages of the different approaches. The **Level of Confidence Approach** provides an automated way of reducing the weakness of the individual approach and increases the accuracy and stability of the SDB model

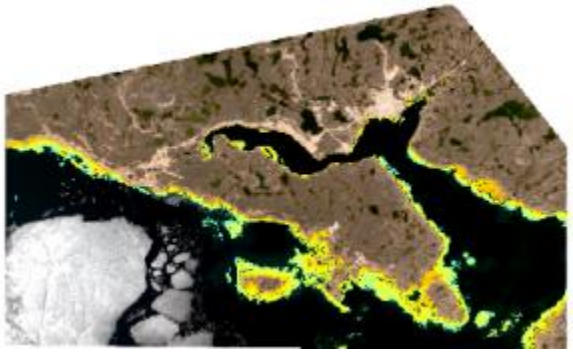
Other advantages of the Level of Confidence approach are :

•Creation of a mask (reduce time of QC to focus on the problematic areas),
•Classification in different CATZOC categories (B & C),
•Increases the confidence in the results (Reduce the SDB uncertainty)

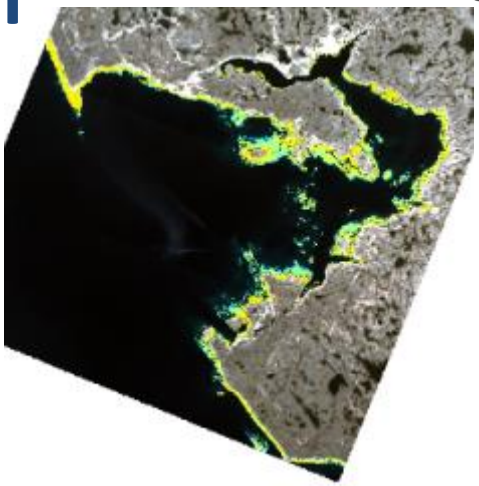
SDB Sensor Selection



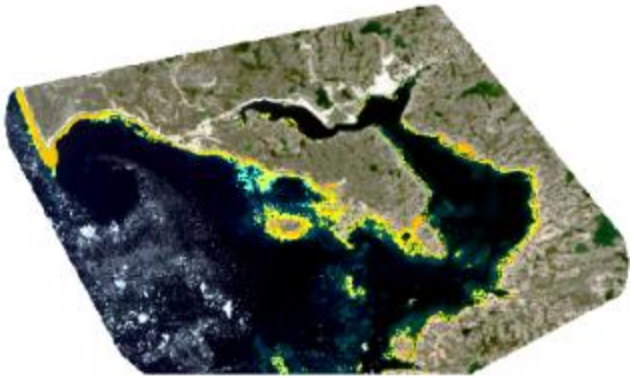
WorldView-2 / 2 m
LE90: 0.88 m



Pléiades / 2 m
LE90: 1.00 m



PlanetScope / 3 m
LE90: 1.32 m

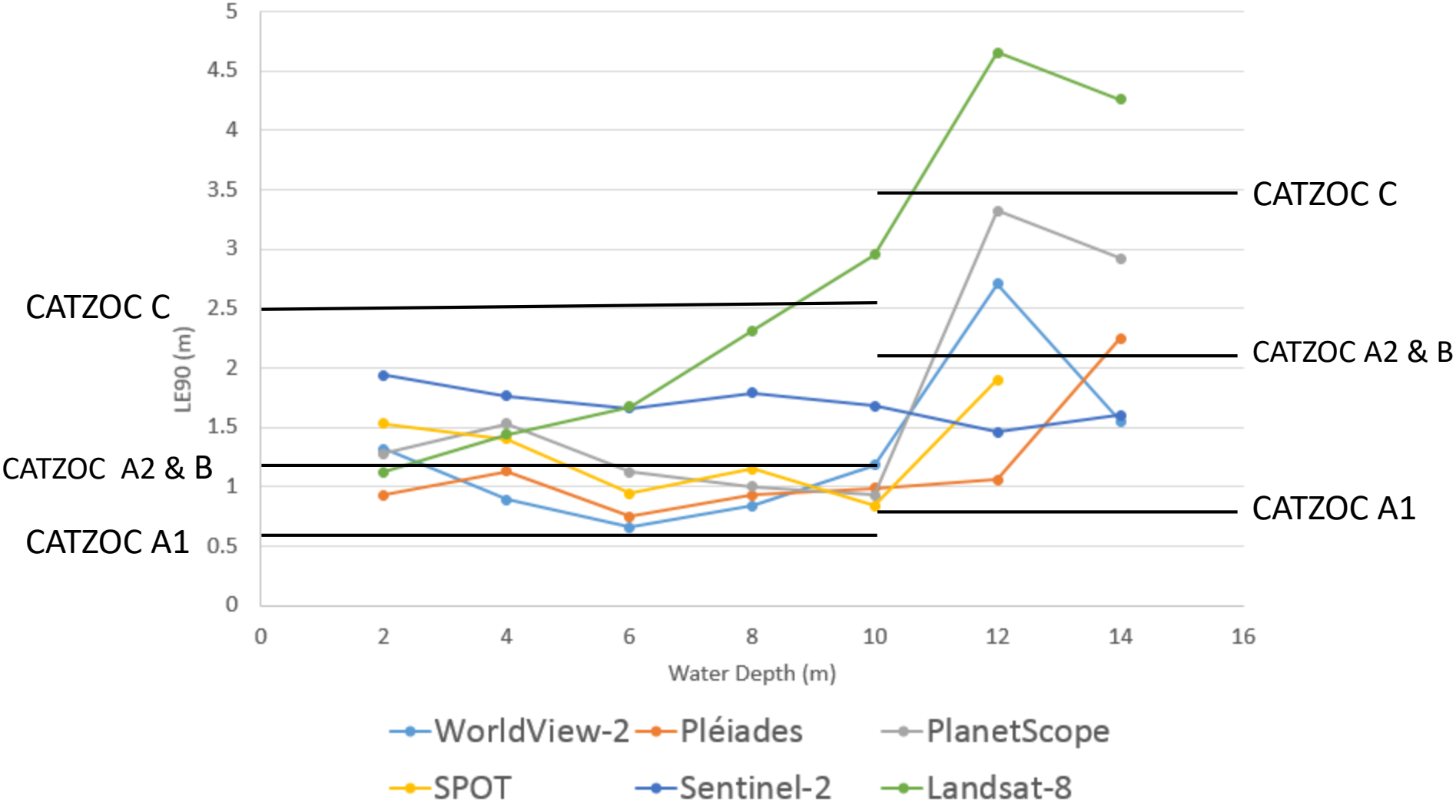


SPOT / 6 m
LE90: 1.30 m

Sentinel-2 / 10 m
LE90: 1.86 m

Landsat-8 / 30 m
LE90: 2.04 m

SDB Sensor Accuracy



Canada

Questions?

Key Contact: Rene.Chenier@dfo-mpo.gc.ca

References:

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2018- Chénier, R.; Faucher, M.-A.; Ahola, R. Shelat, Y. Sagram, M. Bathymetric Photogrammetry to Update CHS Charts: Comparing Conventional 3D Manual and Automatic Approaches. ISPRS Int. J. Geo-Inf. 2018, 7(10), 395; https://doi.org/10.3390/ijgi7100395

2018- Chénier, R.; Faucher, M.-A.; Ahola, R. Satellite-derived bathymetry for improving Canadian Hydrographic Service charts. *ISPRS Int. J. Geo-Inf.* **2018**, *7*, 306, doi:10.3390/ijgi7080306. https://www.mdpi.com/2220-9964/7/8/306