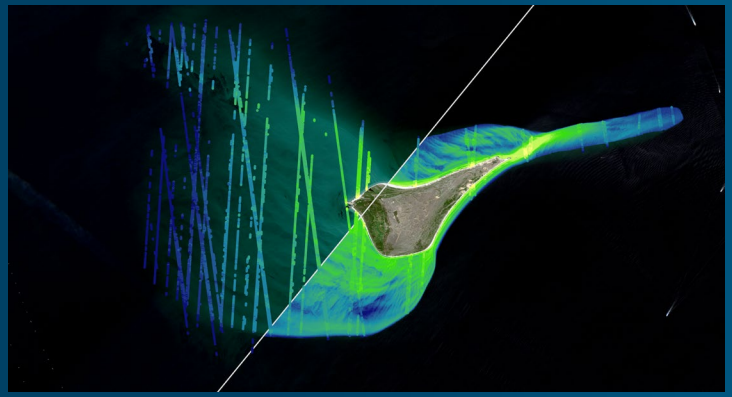
Novel estimation of shallow water bathymetry using ICESat-2 laser altimetry, signal processing and machine learning and Sentinel-2 optical data in a highly automated approach

(Contract 400013325520NLGLC; ESA ITT 2-1745 OSIP)



Reviewed and approved by:
Lars Boye Hansen,
Head of Data Advisory, DHI

Final Review, 10 June 2022

Silvia Huber, Mikkel L. Rasmussen,
Lisbeth T. Nielsen, Andrea Sulova & Lars B. Hansen

Agenda

1. Project Management
2. Achievements of Tasks 1-3
3. Results of Task 4 – Test cases
4. Key achievements, Conclusions & Outlook
5. AOB (Deliverables, CCD, finalising project etc.)

1. Project Management

Project Management - Overview

Task	Task Lead	Description	Month after project start: Phase A: Proof of Concept (1–6) / Phase B: Demonstration of Feasibility and Use (7–18)
1	Lisbeth T. Nielsen	a) Prototyping and testing of workflow for ICESat-2 water depth data extraction	
	Mikkel L. Rasmussen	b) Implementation and testing of fully automated processing of ICESat-2 data	
2	Mikkel L. Rasmussen	a) Processing workflow efficiency improvement testing for SDB and atmospheric corrections	
		b) Optimisation of GPU and implementation for large scale processing	
3	Mikkel L. Rasmussen	a) Evaluation of Bayesian optimization for radiative transfer model parameter estimation	
		b) Implementation of Bayesian optimization scheme into automatic SDB workflow	
4	Mikkel L. Rasmussen	Application and evaluation of automatic SDB workflow based on S2 and ICESat-2	
5	Silvia Huber	a) Management, coordination, reporting	
5	Lars B. Hansen	b) Quality assurance	
		Meetings (*payment milestone)	KO* (1) PM (3) PAR* (6) PM (9) PM* (12) PM (15) FR* (18)

Milestone	Milestone name	Date (month after KO)	Payments (%)
MS-1	Phase A Review (PAR)	T0+6	40
MS-2	Progress Meeting 4 (PM)	T0+12	40
MS-3	Final Review (FR)	T0+18	20
Total			100
Advance Payment (to be offset against MS-1			
AP	Kick-off meeting (KO)	T0	15

KO: Kick off 2nd Dec. 2020

PM: Progress Meeting

PAR: Phase A Review

FR: Final Review

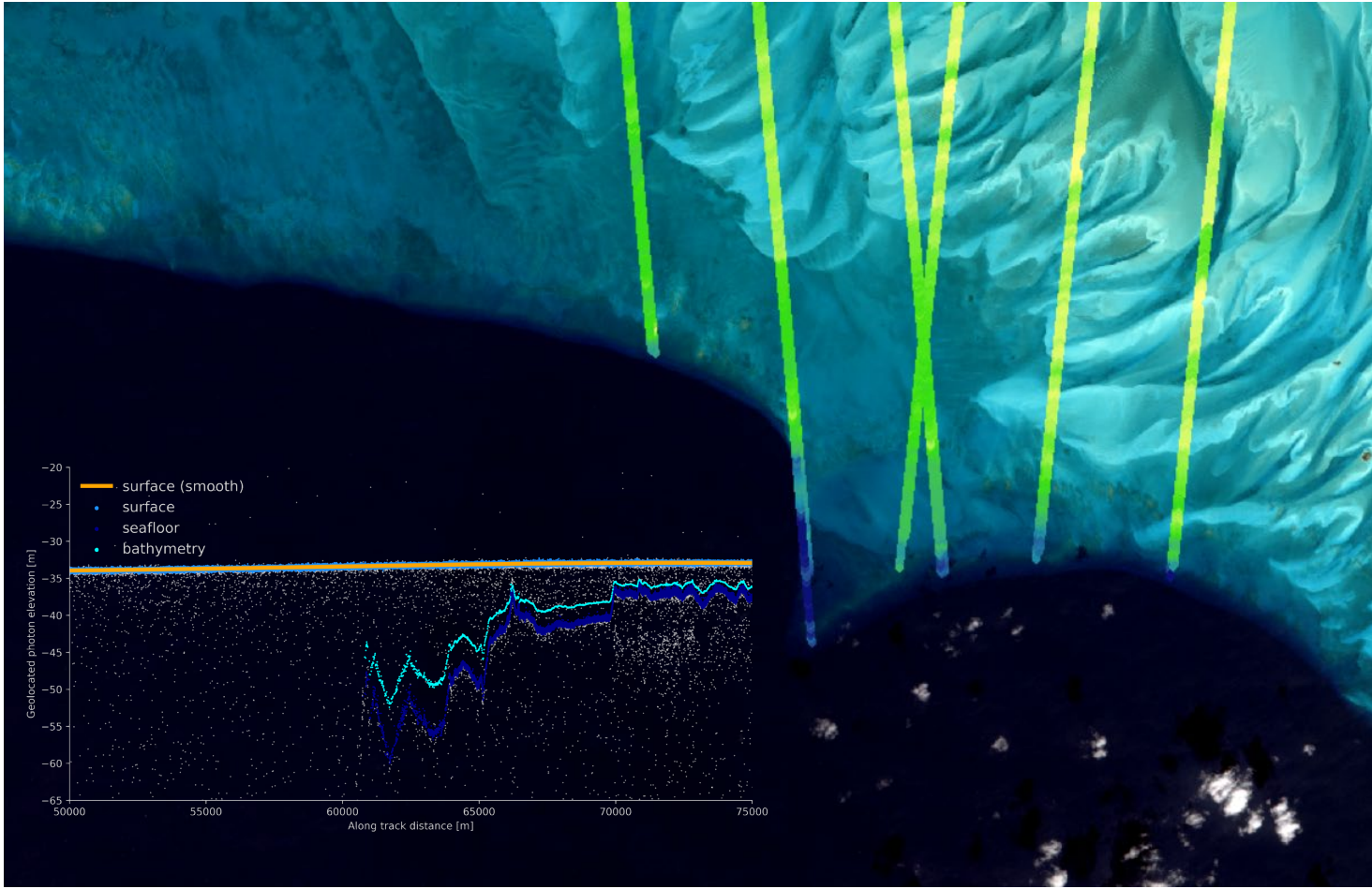
2. Achievements of Tasks 1-3

Task 1: ICESat-2 processing chain

Development of processing chain for automatic extraction of water depth estimates from ICESat-2 laser photon clouds

Achievement

Strong deep learning-based method to efficiently extract accurate and up-to-date calibration and validation data from ICESat-2 photon clouds for SDB production



Task 2: Optimization of processing environment

Optimisation of existing workflows for GPU processing and cloud environments

Achievement

Through optimization of the code and intelligent shortcuts, the processing speed of both the atmospheric correction, and the radiative transfer model has been greatly increased, while maintaining, or improving the quality of the results.

Speed ups of the atmospheric correction

Implementation	Processing time
Per pixel correction	Never finished running
Single value	0:04:01
Simple interpolation	1:16:15 (~19x slower)
Informed interpolation	0:08:22 (~2x slower)

Speed ups of the radiative transfer model

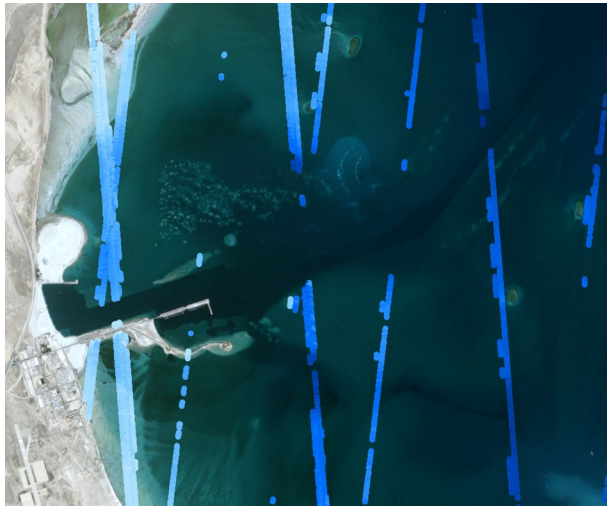
Implementation	Processing time
SciPy	~12 hours
SciPy w. analytical Jacobian	2:31:29 (~5x faster)
Numba	1:04:06 (~11x faster)
GPU	0:15:02 (~50x faster)

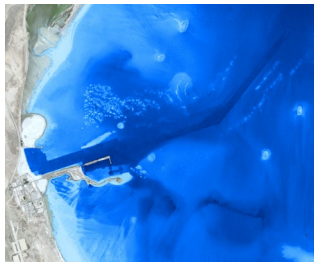
Task 3: Baysian Optimization of model parameter estimation

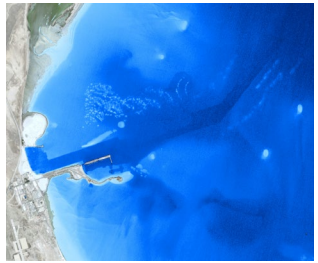
Bayesian optimisation for estimating optimal model parameter for SDB processing

Achievement

Bayesian optimization of hyper parameters for efficiently tuning the radiative transfer model to provide good results with minimal operator effort

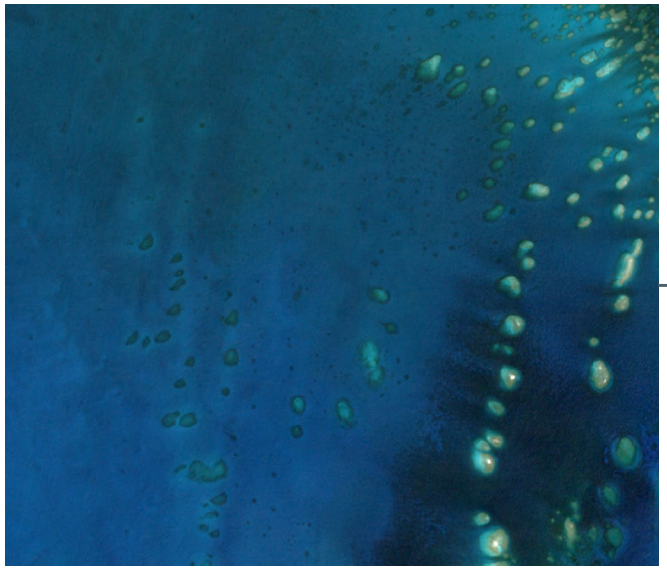




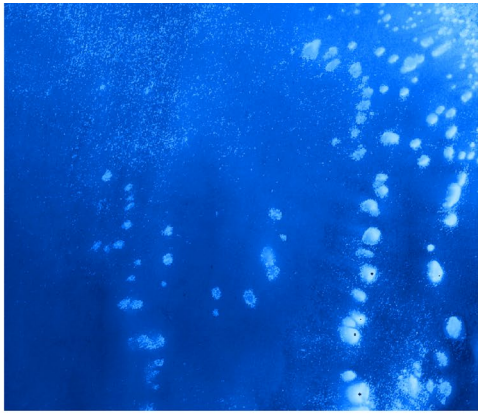


Achievement

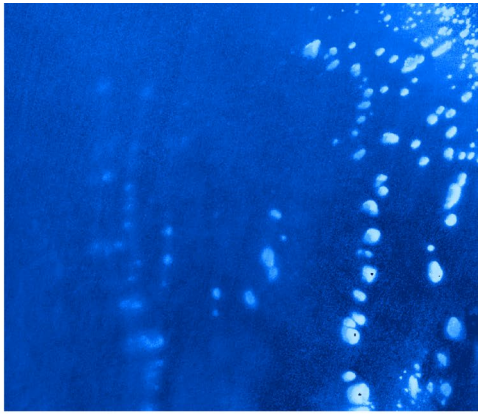
Broadening of the parameter space, in the radiative transfer model, to allow for better representation of the seafloor



Single sea floor type



Double sea floor type



Sea floor type

eel grass — sand

3. Results of Task 4 – Test cases

Task 4: Implementing and testing of automatic workflow

Implementing and testing of automatic workflow in different marine environments

Test sites and marine environments

Test sites

- Denmark
- US Virgin Islands
- Spain
- Australia
- Greenland

- Large scale example Denmark

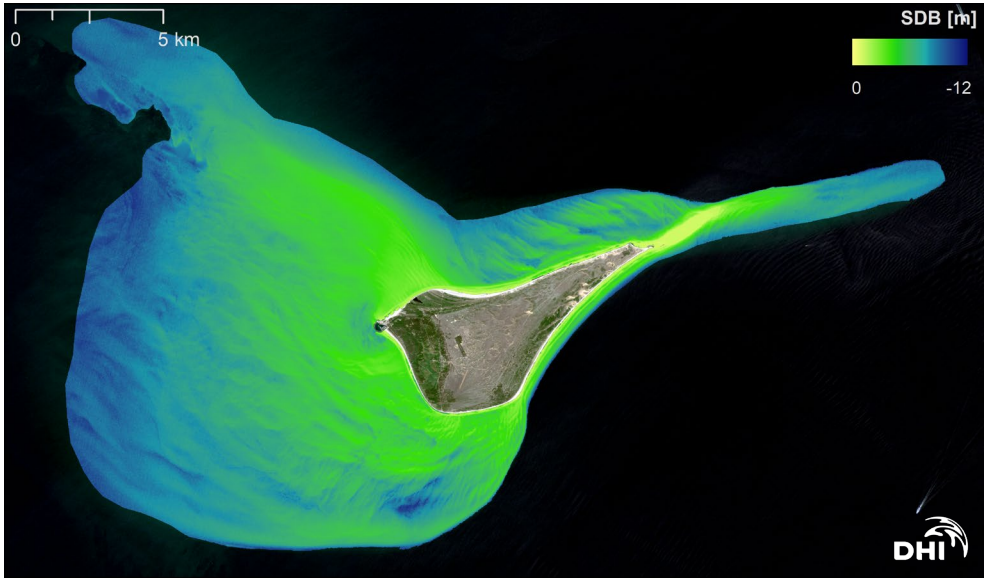
Test environments

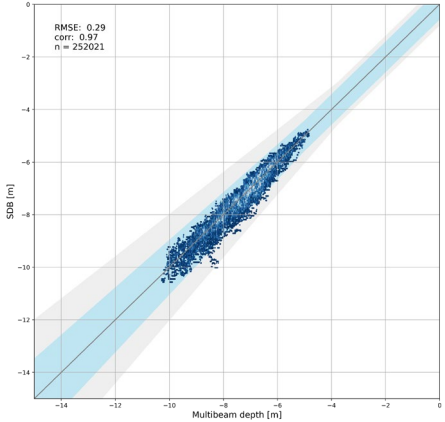
- Range of water quality
- Range of sun elevation angles
- Moderate and steep slopes
- Vegetation and coral reefs
- Waves and surface noise
- Dynamic features

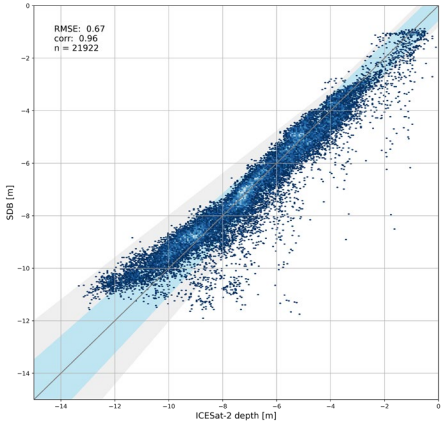
- Availability of survey data

Test Site: Anholt, Denmark

- Low sun elevation angles
- Moderate to high turbidity
- Stable sandbanks and small patches of vegetation

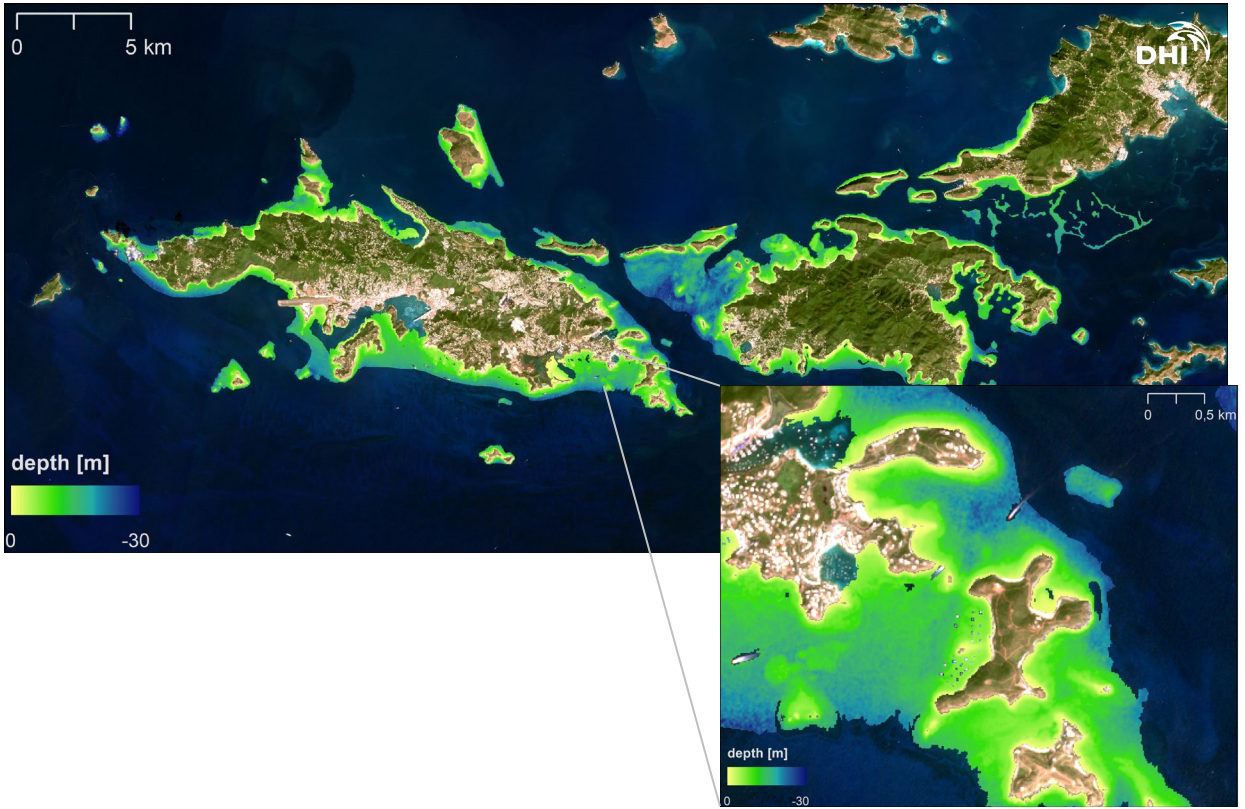






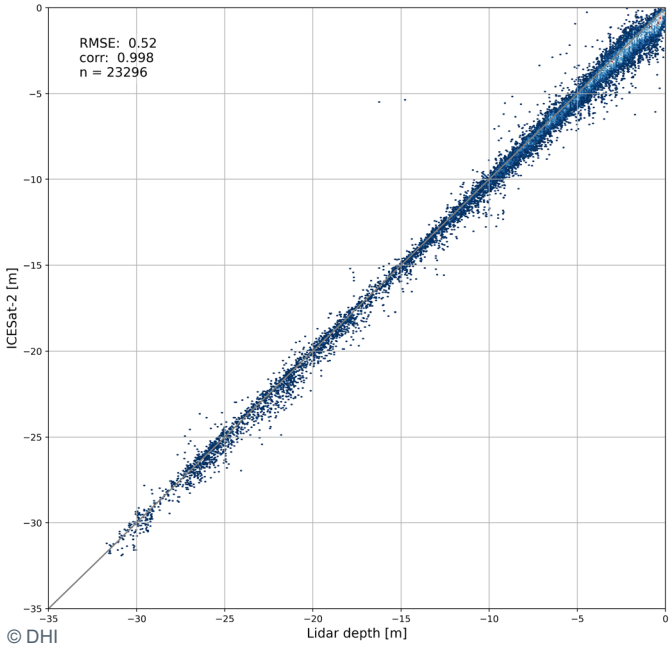
Test Site: US Virgin Islands

- High sun elevation
- Generally good water quality
- Surface waves and scattered clouds
- Coral reefs

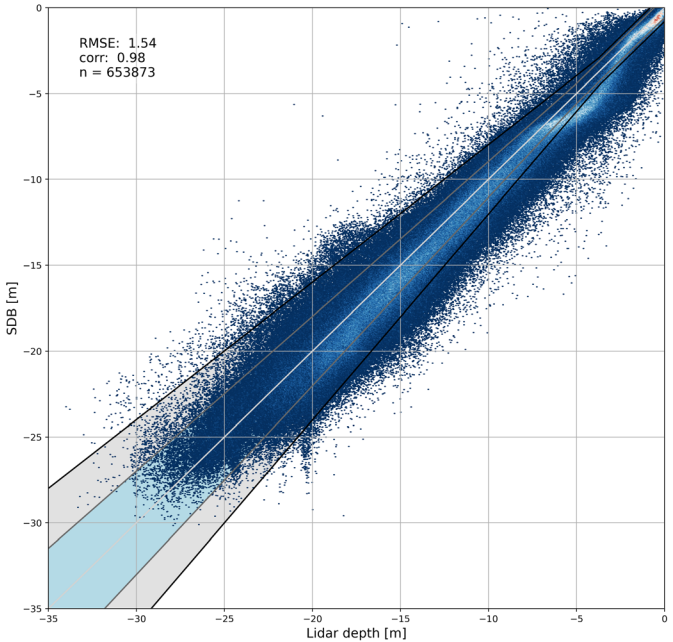


Test Site: US Virgin Islands

- Validation of ICESat-2 against NOAA Lidar survey

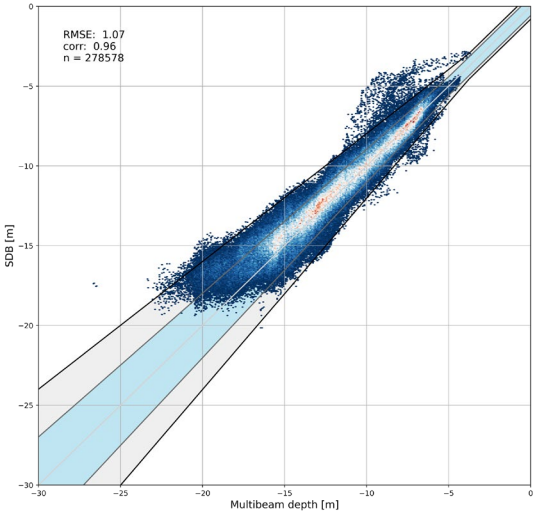


- Validation of SDB against NOAA Lidar survey



Test Site: Tarragona, Spain

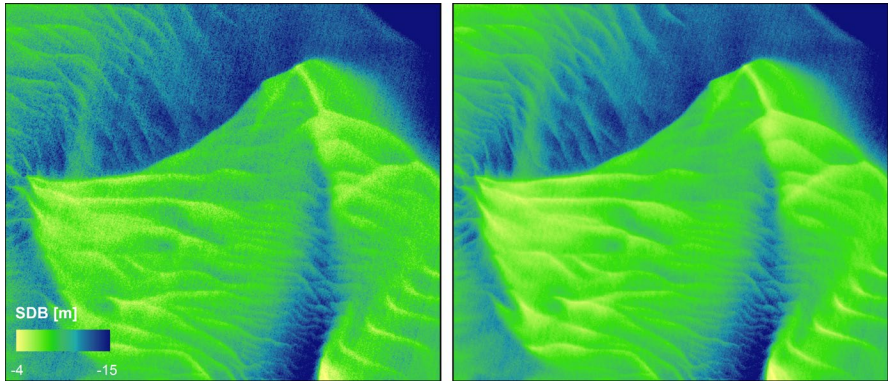
- Generally low turbidity
- Semi-steep slopes
- Patches of vegetation

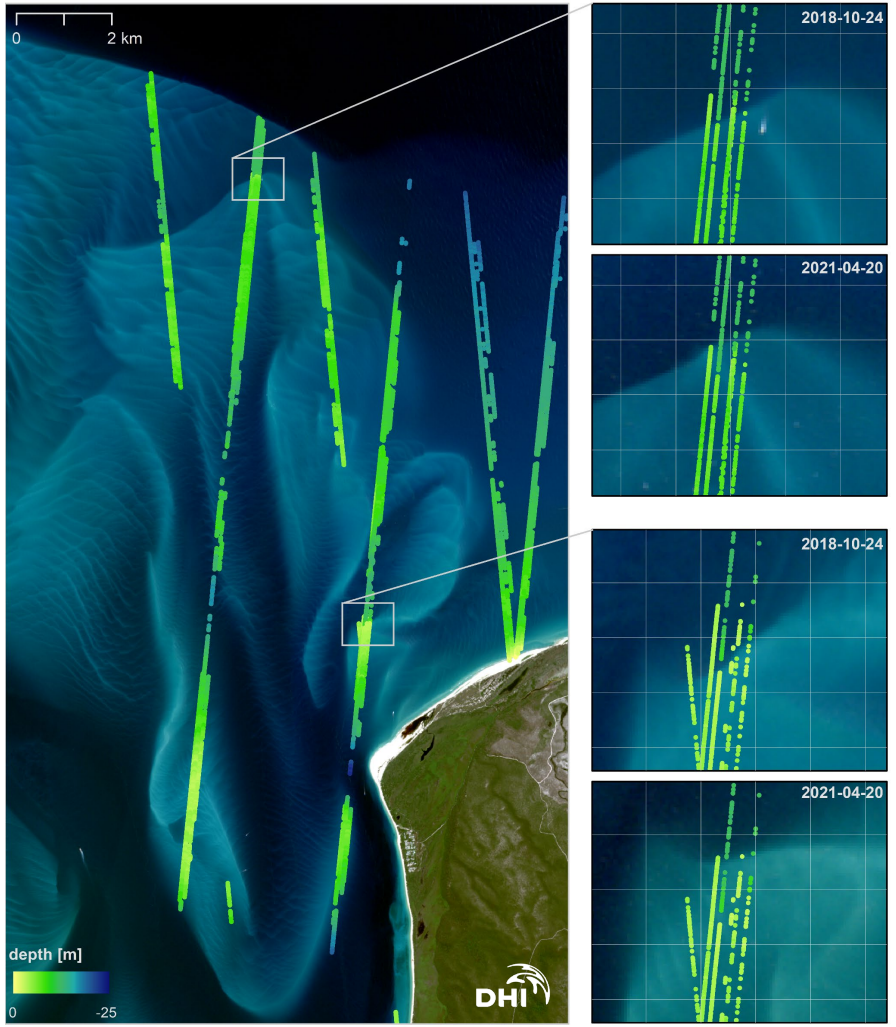


Test Site: Brisbane, Australia

- Dynamic sandbanks
- Excellent water quality

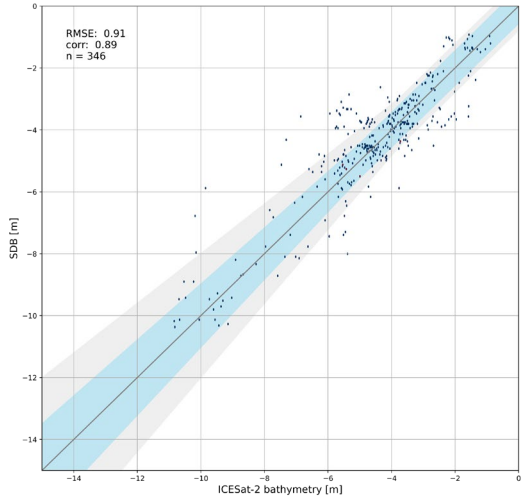
Up-to-date calibration data improves the results

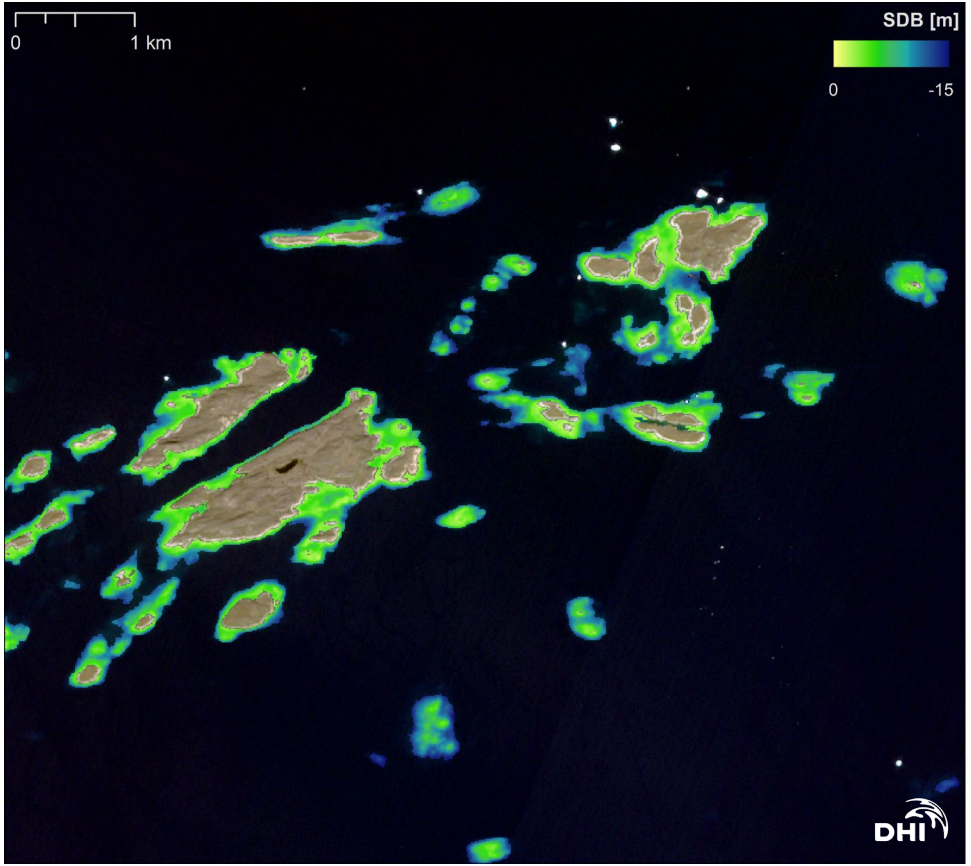




Test Site: Aasiaat, Greenland

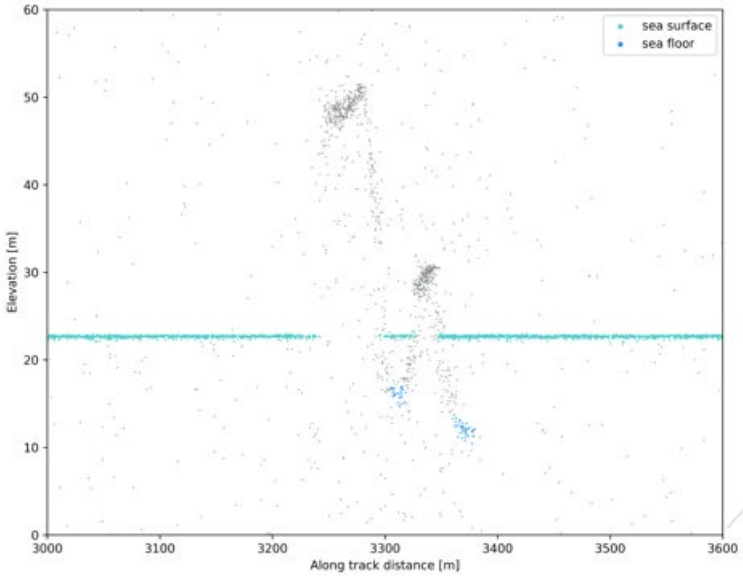
- Very low sun elevation angles and short icefree season
- Steep slopes
- Fixed overpasses

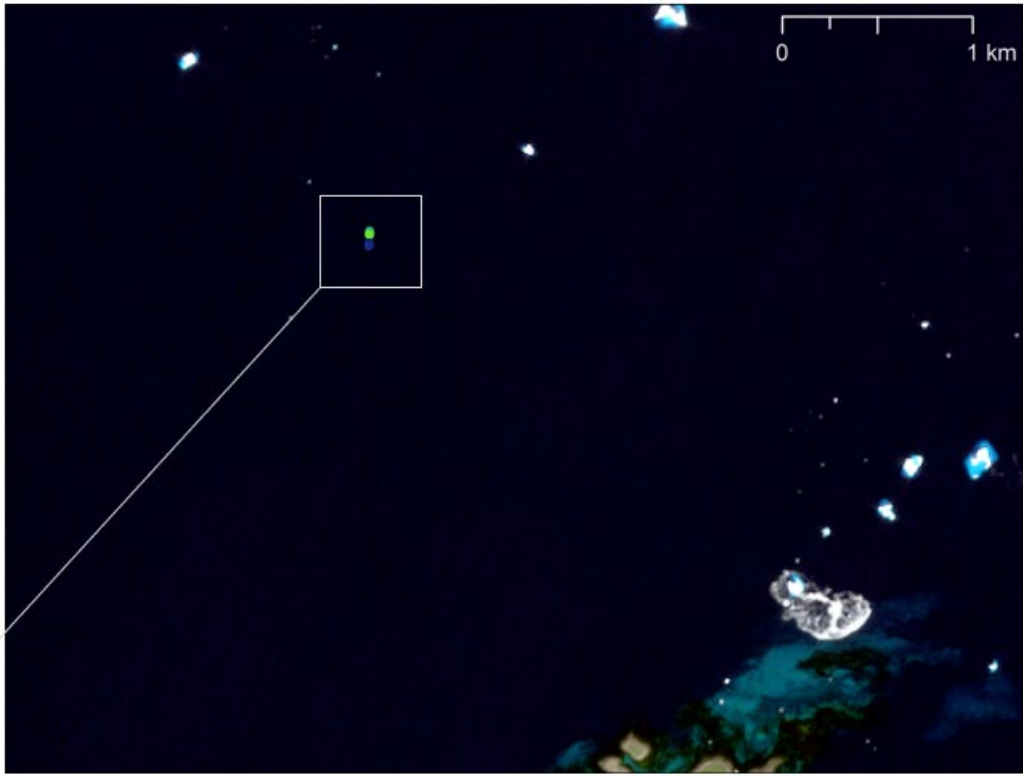




Test Site: Aasiaat, Greenland

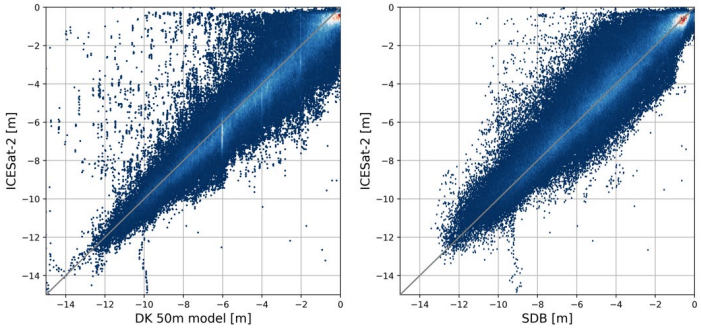
- Special case of false positives: Icebergs have a similar profile as small islands

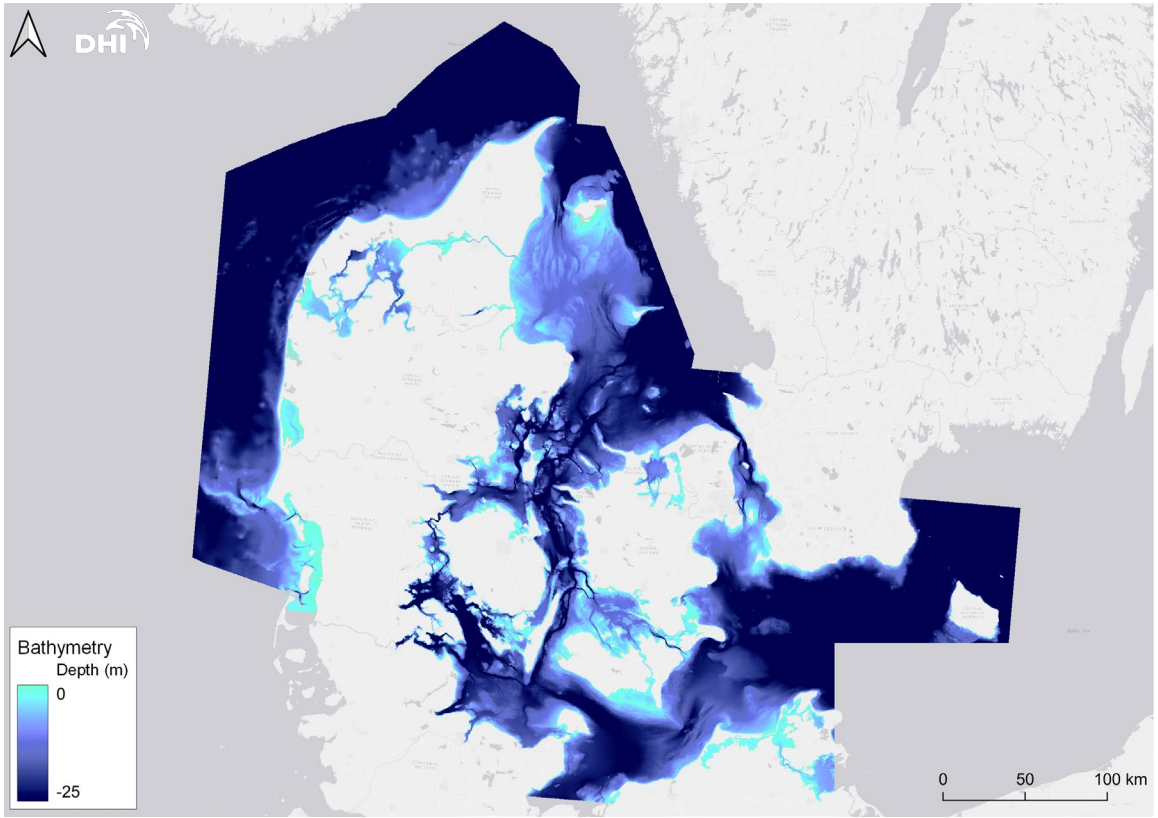




SDB at large scale - Denmark

- Improved representation of actual depths in shallow waters
- Added new data in many small waterbodies, allowing for accurate 2d and 3d modelling





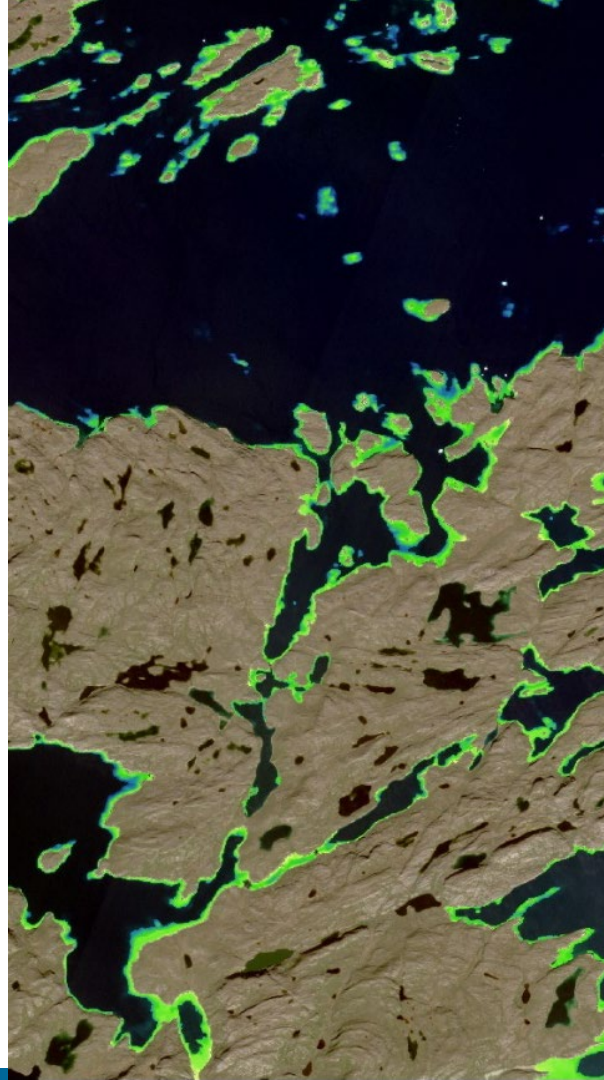
4. Achievements, Conclusions & Outlook

Key technical achievements of the project

- Strong deep learning-based method to efficiently extract accurate and up-to-date calibration and validation data from ICESat-2 photon clouds for SDB production
- Bayesian optimization of hyper parameters for efficiently tuning the radiative transfer model to provide good results with minimal operator effort
- Implementation of the analytical Jacobian for greatly improved processing speed, allowing the Bayesian optimization to be a realistic approach
- Efficient and accurate preprocessing of Sentinel-2 data, through implementation of a new view-angle and correction parameter interpolation scheme
- Broadening of the parameter space, in the radiative transfer model, to allow for better representation of the seafloor

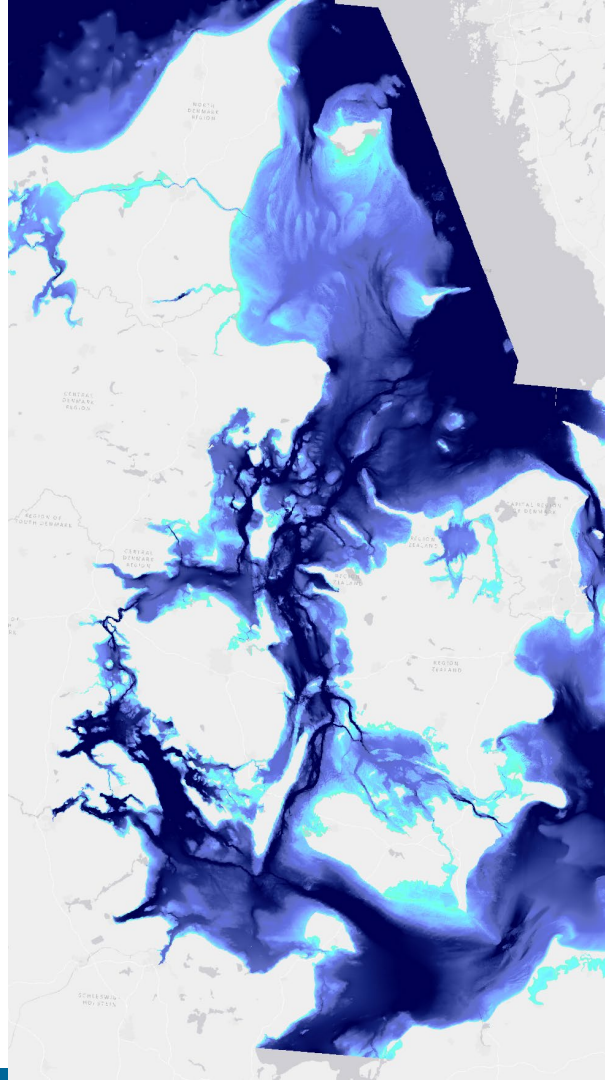
Conclusions

- Major decrease in production time (from days to hours for one S2 tile)
- Higher accuracy of SDB
- Improved quantitative assessments of final SDB
- Reduced production costs
- Reduced dependency on trained operators
- Faster delivery to users



Outlook

- Option to use multi-temporal satellite imagery
- Semi-automatise QC of final SDB
- Explore techniques for reducing high frequency noise in ICESat-2 and SDB results
- Improve tide correction for ICESat-2



5. AOB

- Deliverables (Video etc.)
- CCD (end date)
- Invoicing

List of Deliverables

Submitted

1) Final Report (internal)
2) Executive Summary 5-6 pages for non-expert community (public)
3) Final Presentation (cf. Final Review slides)
4) Technology Achievement Summary: (1 PPT slide)

To be Submitted

5) Technical Data Package (contains final versions of items 1-4)
6) 3-5 min video showcasing the SDB service
7) Contract Closure Documentation (*template submitted for comments, final version to be submitted*)