Product Validation Report
Polar Ocean

Lars Stenseng
PVR, Version 1.0
July 24, 2014

DTU Space
National Space Institute

Product Validation Report - Polar Ocean

Lars Stenseng
National Space Institute
PVR, Version 1.0, Kgs. Lyngby, July 24, 2014

http://www.space.dtu.dk

Document history

Version	Date	Affected sections	Comment
1.0	July 24, 2014		Initial version

Table 1: Document history

Contents

1 Introduction **1**

2 Overview **1**

3 Description of CryoSat-2 Datasets **2**

4 Description of Experimental Datasets **2**
- 4.1 CryoSat-2 Data 2
- 4.2 Independent Datasets 2
  - 4.2.1 DTU13 Mean Sea Surface 2
  - 4.2.2 IceBridge 3

5 Validation Activities **6**
- 5.1 Validation Results 6
  - 5.1.1 Validation against DTU13 Mean Sea Surface Model . . 6
  - 5.1.2 Validation against IceBridge underflights 7
- 5.2 Summary 9

Bibliography **11**

A Acronyms and Abbreviations **13**

1 Introduction

This document describes the procedure used to estimate the errors and validate the Polar Ocean algorithms described in Polar Ocean ATBD(Stenseng, 2014). The sea surface in the sea-ice covered areas does not develop an ocean environment with waves as know from the open ocean. The main concern when validating Polar Ocean algorithm is therefore the sea surface height since other standard ocean parameters are not relevant or can not be estimated due to the nature of the ocean and radar returns in a sea-ice environment with limited area of open water.

The focus is on the Arctic Ocean where CryoSat-2 provides an unique coverage of the high Arctic Ocean, as opposed to the oceans around Antarctica which has been covered by conventional altimetry for decades. Furthermore the impact of improved ocean parameters in sea ice covered regions is believed be greater in the Arctic Ocean where ship traffic is likely to increase in the future.

2 Overview

The validation of the Polar Ocean algorithms concerns two conceptual very different issues. First, the methodology for identifying and selecting returns from sea-ice leads must be validate to ensure that only correct and valid returns are used for further validation. Next, the valid returns can be used to validate the algorithms for estimation of the lead sea surface heights against independent observations. Finally, all retracked heights of returns classified as useful leads, by the methods described in the Polar Ocean ATBD, are validated against independent observations to a realistic estimate of the unsupervised Polar Ocean algorithms.

The availability of independent and reliable datasets useful for validation of the Polar Ocean algorithms is indeed very sparse and most of these will only allow for one type of the validations. Coastal tide-gauges in the Arctic are often affected by the fast-ice which can extend several hundred km from the coast, leaving no leads and thereby effectively block the radar retrieval of the sea surface height.

3 Description of CryoSat-2 Datasets

The CryoSat-2 datasets use for the validation described in this document are have all been processed using an experimental extension to the DTU Space altimetry processing system LARS. The main source of input data for producing the Polar Ocean product is the ESA Baseline-B SAR L1b product, which currently covers most of, if not, the entire CryoSat-2 period and thus provides a consistent dataset from mid July 2010 to present.

4 Description of Experimental Datasets

4.1 CryoSat-2 Data

The CryoSat-2 data have primarily been chosen to match the IceBridge flights. The geophysical corrections of the CryoSat-2 observations is performed using the corrections supplied within the ESA Baseline-B product. Furthermore April 2013 have been chosen for comparison with the DTU13 Mean Sea Surface (MSS) (Stenseng and Andersen, 2013; Stenseng et al., 2014).

4.2 Independent Datasets

To minimize errors introduced by correction of tides, barometric and other temporal effects, the validation dataset and the CryoSat-2 dataset should be obtained within a short time. Furthermore the sea-ice cover is drifting up to 500 m/h and drift correction must be considered for leads identified in the validation dataset.

Investigation of the suggested sources for validation of the Polar Ocean product indicates that the CryoSat-2 underflights in the IceBridge dataset offer the overall most useful validation dataset and is therefore the main focus of the validation.

4.2.1 DTU13 Mean Sea Surface

The DTU13 MSS represent the latest generation of the state of the art Mean Sea Surfaces. DTU13 has been derived from a number of satellite altimeter missions, e.g. ERS-1, ERS-2, and ENVISAT, from a period of 20 years. Above 82° DTU13 is based on CryoSat-2 data from 2012 processed with the LARS system and care should therefore be taken when evaluating the CryoSat-2 datasets from 2012.

4.2.2 IceBridge

The NASA IceBridge mission, initiated in 2009, is an airborne cryosphere monitoring mission established to collect LiDAR and RADAR data in Arctic and Antarctica. The mission aims to provide the essential observations needed to bridge the time series between the Ice, Cloud and Land Elevation Satellite (ICESat) and the upcoming ICESat-2 misssion (NASA IceBridge, 2014).

Since the launch of CryoSat-2 a number of underflights has been carried out during the IceBridge campaigns when there was an suitable opportunity. Table 2 list the underflights carried out in the Arctic from 2011 to 2013.

A number of flight over the Arctic ocean found most suitable for the validation has been selected and can be seen together with the corresponding CryoSat-2 profile in Figure 1.

For the validation activities the ATM (Krabill, 2014a), NSATM (Krabill, 2014b), and Digital Mapping System Camera (DMS) (Dominguez, 2014) products have been used.

Operation IceBridge Greenland/Arctic Sea Ice 2011

Date	Flight	Mission	ATM	DMS	CS-2 Orbit
17/03/2011	F02	Sea Ice CryoSat-2 Underflight	x	x	4979
23/03/2011	F05	Sea Ice - ICEX Camp Survey / Fairbanks	x	x	N/A
29/03/2011	F09	CryoSat Land Ice	x	x	5138
15/04/2011	F20	Sea Ice CryoVEx	x	x	5399
26/04/2011	F27	Geikie 01	x	x	N/A
05/05/2011	F32	Devon Ice Cap - CryoVEx	x	x	N/A

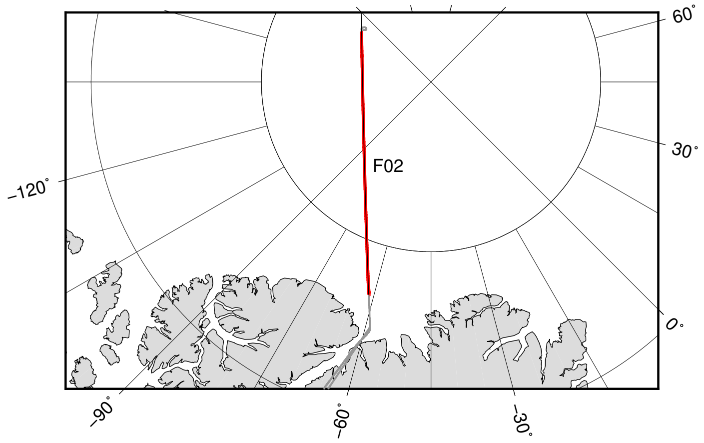
Operation IceBridge Greenland/Arctic Sea Ice 2012

Date	Flight	Mission	ATM	DMS	CS-2 Orbit
15/03/12	F02	Beaufort-Chukchi Zigzag	x	x	10262 10263
17/03/12	F04	Alaska Coastal Zigzag A	x	x	10291 10292
21/03/12	F06	Sea Ice - North Pole Transect	x	x	10346
26/03/12	F09	Wingham Box	x	x	10421
28/03/12	F11	CryoSat-2 underflight & Inglefield Bredning/Qaanaaq	x	x	10450
29/03/12	F12	ZigZag West (modified) & ESA CryoVEx	x	x	10462
30/03/12	F13	Cryoland	x	x	10482
02/04/12	F15	Fram Gateway (modified) & ESA CryoVEx	x	x	10520

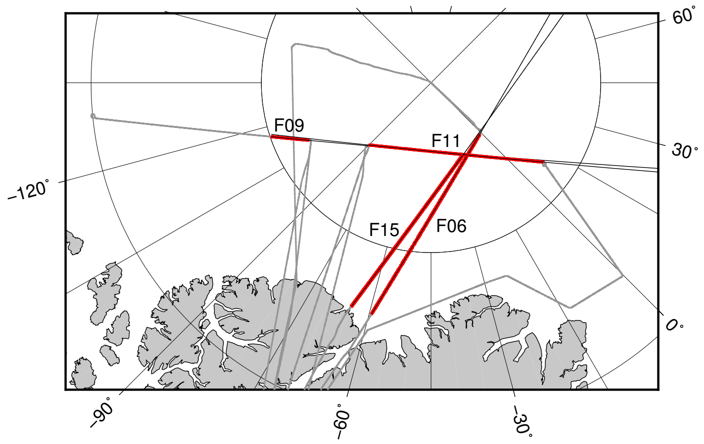
Operation IceBridge Greenland/Arctic Sea Ice 2013

Date	Flight	Mission	ATM	DMS	CS-2 Orbit
20/03/13	F01	Sea Ice - CryoSat-2	x	x	15632
24-25/03/13	F05	Sea Ice - SIZRS ZigZag	x	x	N/A
24/04/13	F24	Sea Ice - North Pole Transect	x	x	16139

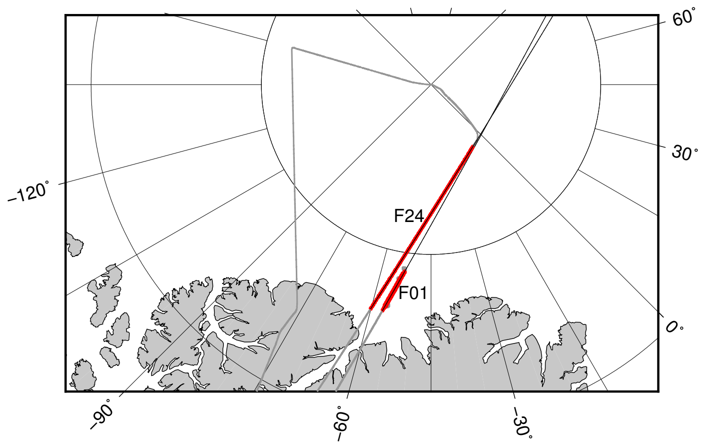
Table 2: Overview of all IceBridge flights listed as CryoSat-2 underflights. The three rightmost columns indicate the availability of laser height measurements, aerial photos, and CryoSat-2 absolute orbit number.



(a) 2011



(b) 2012



(c) 2013

Figure 1: Overview of selected IceBridge flights from 2011-2013 in gray with used sections in red. The related CryoSat data segments are overlaid in black.

5 Validation Activities

The validation activities falls into two categories for the Polar Ocean. The first validation activity is the overall validation of the developed classification scheme and retracking procedures. To obtain a statistical useful result the validation need to be performed on a larger dataset which for the Polar Ocean implies a comparison with a mean sea surface model, in this case the DTU13 model.

The second validation activity is the high detail comparison with a subset of the IceBridge dataset. The IceBridge dataset can truly be considered independent of the CryoSat-2 data but due to the limited temporal and spatial coverage it is primarily useful for validation of the lead classification. Secondary the IceBridge dataset can be used to evaluate the true height offset by comparison of the laser derived lead water heights from the ATM with the produced CryoSat-2 heights.

5.1 Validation Results

5.1.1 Validation against DTU13 Mean Sea Surface Model

ESAs Kiruna Baseline-B CryoSat-2 L1b data from April 2013 have been processed with the LARS system to obtain the values for the sea surface height. In the validation only observations above 70° North has been used and filtering of outliers has been applied. Furthermore only profiles with more than 100 accepted observations are used in the statistics. All together this results in 653 profiles with a total 413897 sea ice lead heights.

The frequency of useful leads in a profile is highly variable and the way to calculate statistics must be considered carefully. In this study each profile (i.e. retracking of one L1b SAR file) has been used to calculate one mean value and the standard deviation of the found mean. Figure 2 and Figure 3 show histograms of the mean values and standard deviations of the profiles.

The overall mean offset between the one month data and DTU13 MSS is found to be -1.435 m, of which -0.710 m arises from the difference between the datums used in DTU13 and CryoSat-2. Furthermore Scagliola and Fornari (2013) gives a range bias on the Baseline-B SAR product which accounts for additional -0.673 m, resulting in a total bias for the Polar Ocean product of 5.2 cm. The mean standard deviation of the mean for all the profiles is found to be 7.4 cm.

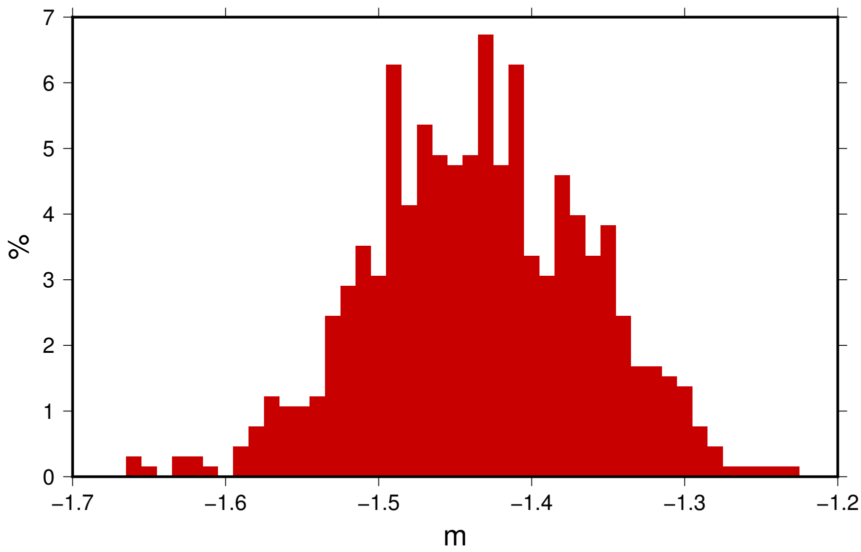


Figure 2: Histogram of percentage of profiles with a given mean difference with respect to DTU13.

5.1.2 Validation against IceBridge underflights

To identify sea ice leads in the IceBridge DMS photos a program have been developed. The program rely on the high contrast of a dark sea ice lead against the bright white snow to outline the individual leads. The centroid and the area of the outline is output together with the outline polygon coordinates. Next the polygon coordinates are used to select ATM and NSATM point to derive the elevation of the sea ice leads.

In Figure 4 is shown an example of an IceBridge DMS photo together with the outline of the detected sea-ice leads.

Of the investigated IceBridge flights only three proved to be of sufficient quality for the intended investigations. Figure 5 show the area, in red, of the detected sea ice leads as a function of the along-track position along the CryoSat-2 ground track. Included in the figure is also the detected sea ice leads from the CryoSat-2 dataset marked with blue. From the figure it can be seen that in general leads larger than 700 m^3 is detectable in CryoSat-2 data using the developed method.

The used IceBridge photos cover an area which is approximately 500 m wide. The cross-track width observed by CryoSat-2 is much wider than 500 m and therefore more sea-ice leads are found in the Polar Ocean product. For the further analysis only leads observed in both the DMS, the ATM and

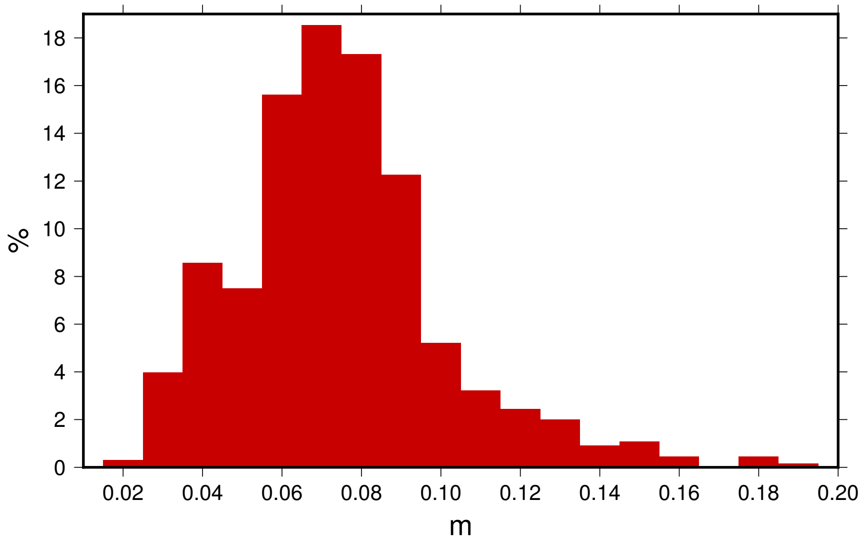


Figure 3: Histogram of percentage of profiles with a given standard deviation of the mean difference with respect to DTU13.

the Polar Ocean product will be considered. Furthermore it should be noted that in the comparison with IceBridge the correction for ocean tides and barometric effects has been removed from the Polar Ocean product to make the CryoSat-2 observations comparable.

The high specular leads also influences the LiDAR and due to the higher incident angle the ATM is found to give much fewer returns over leads than the NSATM and therefore only the NSATM is used in the comparison. Using the NSATM the average height of each sea-ice lead is calculated and a standard deviation of the mean height is found to be of the order of 2 to 5 cm.

Date	No. leads in DMS	Colocated leads in CS-2	% detected in CS-2
20130424	12	11	92%
20120402	25	21	84%
20120321	7	2	28%

Table 3: Sea-ice leads found in DMS photos and in CryoSat-2 data at same location.

Finally the difference between the Polar Ocean retracked data and the IceBridge datasets can calculated and the Scagliola and Fornari (2013) correction can be applied, see Table 4. The statistic presented in this IceBridge

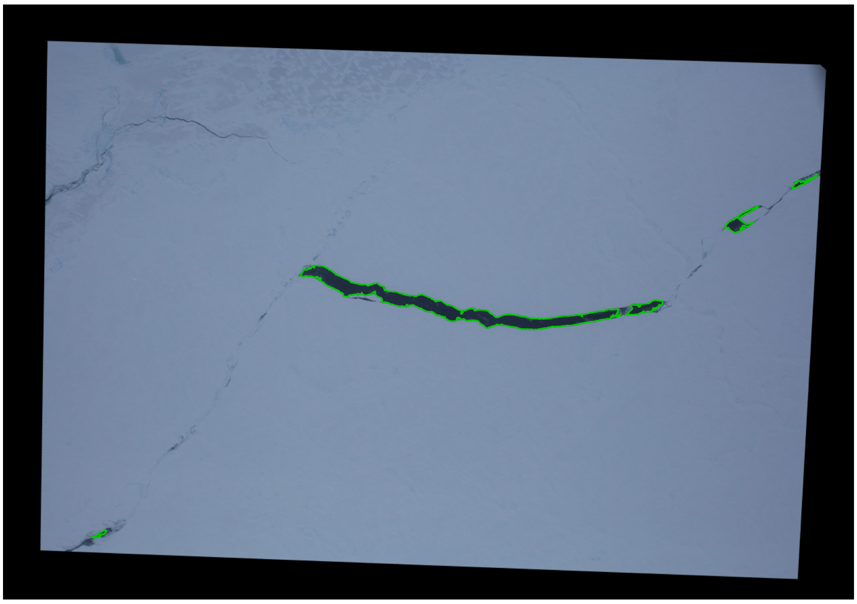


Figure 4: Example of an IceBridge DMS photo overlayed with the outline of the detected sea-ice lead features in green.

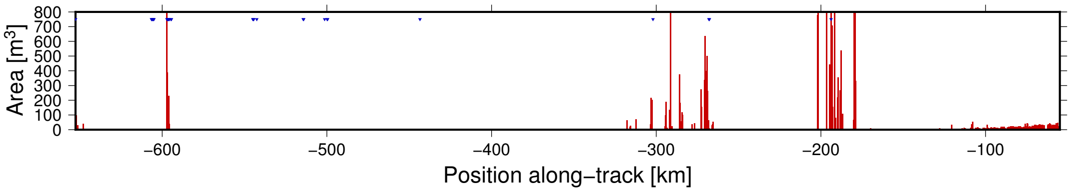
study should be considered in the light of the very few measurements. Calculating the overall mean difference of the corrected values results in 0.0 cm.

Date	No. points	Mean	Corrected mean	Std. dev.
20130424	11	-0.602 m	0.071 m	4.5 cm
20120402	21	-0.709 m	-0.036 m	10.9 cm
20120321	2	-0.777 m	-0.104 m	0.6 cm

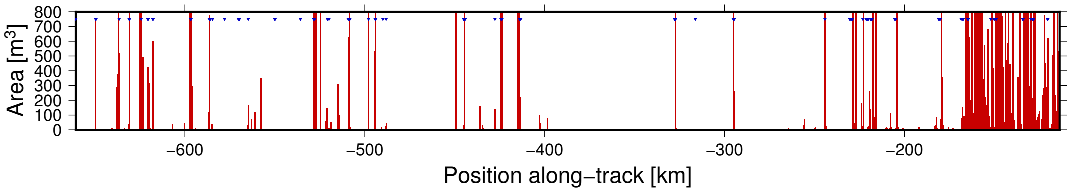
Table 4: Mean differences and std. dev. between CryoSat-2 and IceBridge NSATM.

5.2 Summary

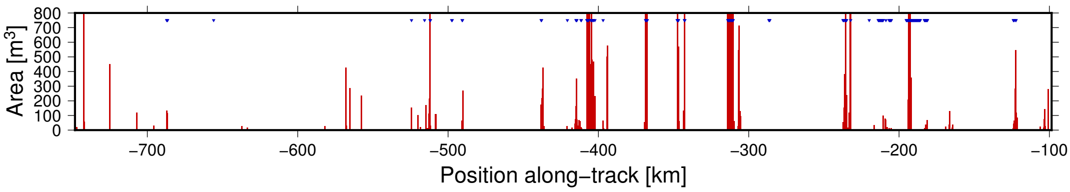
The validations presented here clearly demonstrates the quality of the results obtained from the CP4O developed methods for Polar Oceans. In the comparison with the DTU13 Mean Sea Surface a mean offset of 5.2 cm and a standard deviation of the mean of 7.2 cm was found, applying only very coarse outlier rejection. In the comparison with the IceBridge underfligths a



(a) March 21st 2012



(b) April 2nd 2012



(c) April 24th 2013

Figure 5: Along-track position of identified leads in CryoSat-2 data in blue and leads identified in IceBridge DMS photos in red columns with height indicating the area of the lead.

mean offset of 0.0 cm and a standard deviation of the mean of between 5 and 10 cm was found, but the amount of useful IceBridge data was not optimal.

Bibliography

Dominguez, R. (2010, updated 2014). IceBridge DMS L1B geolocated and orthorectified images. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.

Krabill, W. B. (2013, updated 2014a). IceBridge ATM L1B elevation and return strength. version 2. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.

Krabill, W. B. (2014b). IceBridge narrow swath ATM L1B elevation and return strength. version 2. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.

NASA IceBridge (2014). National snow and ice data center - IceBridge bridge to CryoSat-2.

Scagliola, M. and Fornari, M. (2013). Known biases in cryosat level1b products. Technical Report C2-TN-ARS-GS-5135, Aresys.

Stenseng, L. (2014). Algorithm theoretical baseline document - polar ocean. Technical report, DTU Space, National Space Institute.

Stenseng, L. and Andersen, O. B. (2013). Improving the arctic mean sea surface with cryosat-2 data. In *2013 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec.*, number G41B-0937.

Stenseng, L., Andersen, O. B., and Knudsen, P. (2014). Enhancing the arctic mean sea surface and mean dynamic topography with cryosat-2 data. In *Geophysical Research Abstracts*, volume 16.

A Acronyms and Abbreviations

ATBD	Algorithm Theoretical Baseline Document
ATM	Airborne Topographic Mapper (IceBridge payload)
DMS	Digital Mapping System (IceBridge payload)
DTU Space	National Space Institute, Technical University of Denmark
ESA	European Space Agency
ICESat	Ice, Cloud and Land Elevation Satellite
LARS	LARS the Advanced Retracking System
LiDAR	Light RADAR or Light Detection And Ranging
MSS	Mean Sea Surface
NASA	National Aeronautics and Space Administration
NSATM	Narrow Swath Airborne Topographic Mapper (IceBridge payload)
PVR	Product Validation Report

DTU Space
National Space Institute
Technical University of Denmark

Elektrovej 327
DK-2800 Kgs. Lyngby

Tel +45 4525 9500
Fax +45 4525 9575

http://www.space.dtu.dk