ESA–MOST Dragon Cooperation

中国科技部-欧洲空间局“龙计划”合作

2017 DRAGON 4 SYMPOSIUM

2017年“龙计划”四期学术研讨会

An improved sea ice freeboard retrieval algorithm for Cryosat-2 data

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26–30 June 2017 | Copenhagen, Denmark

2017年6月26-30日，丹麦 哥本哈根

Outline

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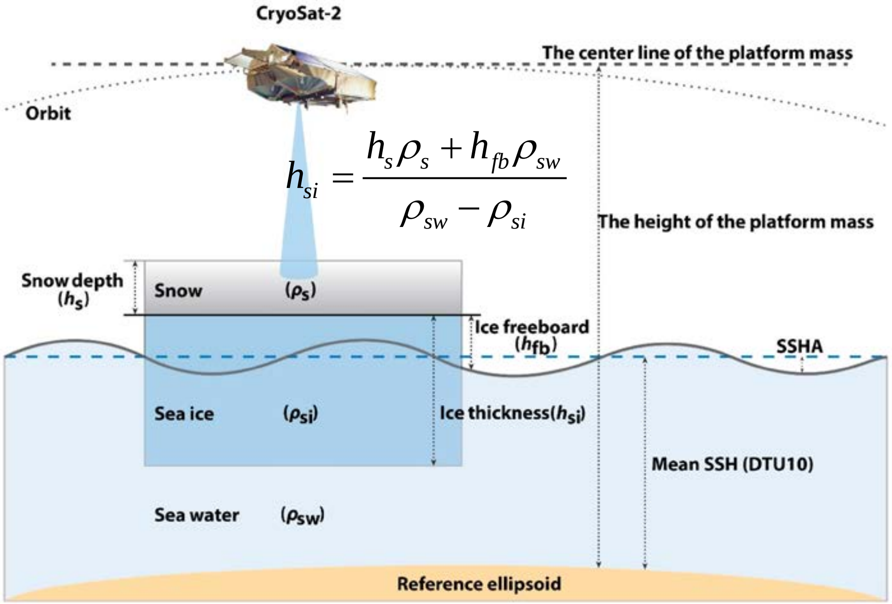
IV. Validation

V. Conclusions and next planning

I. Introduction

Using new generation altimeters (CryoSAT-2 and Sentinel-3) to improve sea ice thickness retrieval accuracy is a important task in our project.



<u>Two-stage design for ice thickness retrieval</u>:

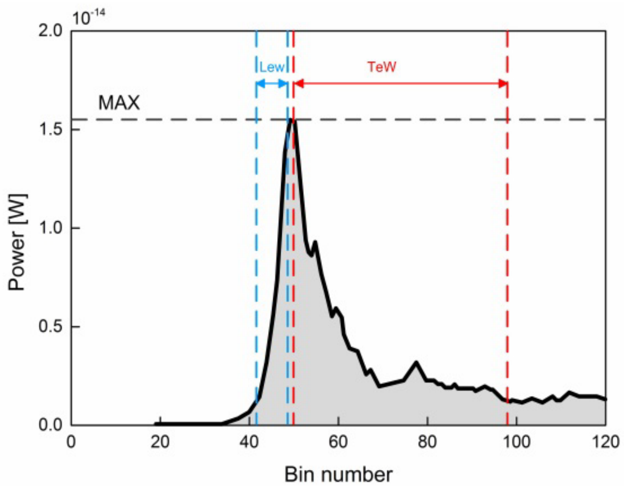
- Phase I: sea ice freeboard detection.
- Phase II: sea ice thickness detection.

- Ice freeboard: ice-water discrimination, waveform retracking to get surface elevation.
- Sea ice density: sea ice types classification.

II. Sea ice types classification

We compare a variety of machine-learning classification techniques, and aim to find the optimal classifier-features combination to improve the accuracy of sea ice classification.

Features	Definition
PP	$\mathrm{PP} = P_{\max} / \sum_{i=1}^{256} P_i$
LeW	The distance between 1% and 99% of the maximum power (rising edge)
TeW	The distance between the 99% and 1% of the maximum power (falling edge)
MAX	Maximum power value of the echo waveform
SSD	The standard deviation of power values
Sigma0	Radar backscatter coefficient

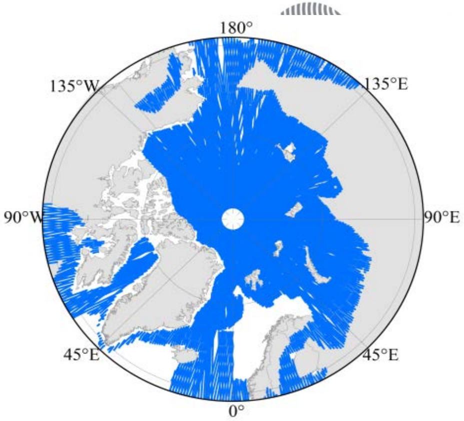


Classifiers
Bayesian
K nearest-neighbor
Support vector machine
Random forest
Back propagation neural network
Convolutional neural network

Cryosat-2 Data

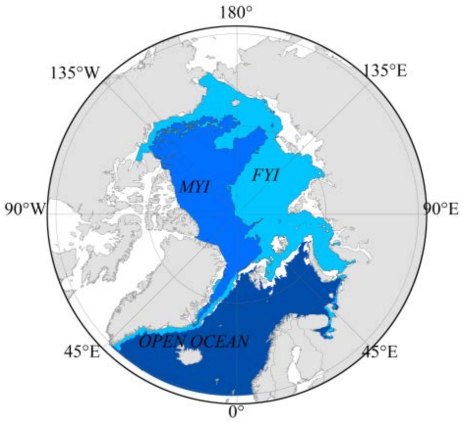
- Area: Arctic
- Data set: Cryosat-2 L1b
- Time coverage: 03/2015 + 11/2015 + 03/2016
- Mode: SAR mode

a



Validation data

- Data set: ice charts published by the Arctic and Antarctic Research Institute (AARI)
- Source: satellite and reports from coastal stations and ships
- Process: 2 km grid in north polar stereographic projection



Use 15,000,000 training samples (altimeter surface points), and execute100 times test to find the best classifier and its corresponding best features.

Joint feature and classifier selection algorithm

Initialization:

$f \in F$, $F = \{f_1, f_2, f_3, f_4, f_5, f_6\}$,

$c \in C$, $C = \{ C_1, C_2, C_3, C_4, C_5, C_6\}$,

$F_i = \{\Phi\}$, $i = 0$

Iteration:

1. Select the best new feature:

$f^+ = \arg\max_{f \notin F_i} \Psi\,(F_i + f, s, c)$

$F_i = F_i + f^+$, $s_i = s$, $c_i = c$, $i = i+1$

2. Select the worst existing feature:

$f^- = \arg\max_{f \in F_i} \Psi\,(F_i - f, s_i, c_i)$

3. Conditional judgmental:

if $\Psi\,(F_i, s_i, c_i) < \Psi\,(F_i - f^-, s_i, c_i)$

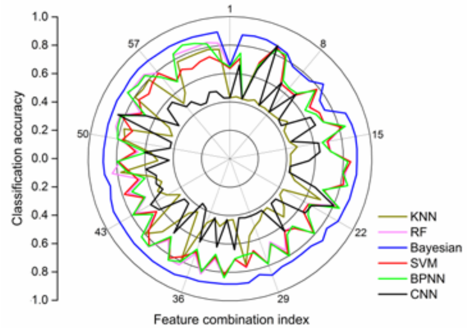
then $F_i + 1 = F_i - f^-$, $s_i + 1 = s_i$, $c_i + 1 = c_i$, $i = i + 1$,

go to Step 2

else go to Step 1

end if

<u>Optimal classifier</u>: Bayesian



<u>Feature importance</u>: LeW, SSD, TeW , PP, Sigma0, MAX

Feature	Rank	CNN	KNN	RF	Bayesian	SVM	BPNN
LeW	1	1.00	0.88	1.00	0.00	0.49	1.00
SSD	2	0.50	0.03	0.03	0.25	1.00	0.46
TeW	3	0.00	1.00	0.05	0.31	0.02	0.47
PP	4	0.33	0.00	0.00	1.00	0.00	0.64
Sigma0	5	0.48	0.06	0.08	0.81	0.09	0.00
MAX	6	0.47	0.27	0.03	0.49	0.04	0.04

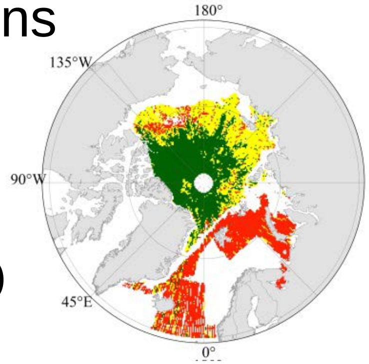
The top-4 classifier-features combinations

① Bayesian & (LeW + SSD + TeW + PP)

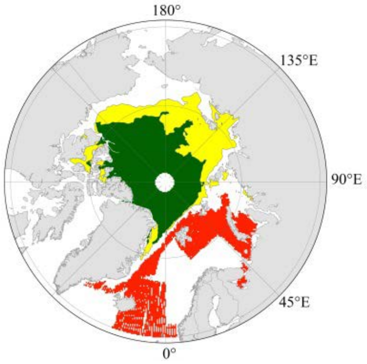
② Bayesian & (MAX+ TeW)

③ RF & (LeW + SSD + TeW + PP + MAX + Sigma0)

④ KNN & (LeW + SSD + TeW + PP)



Classification result

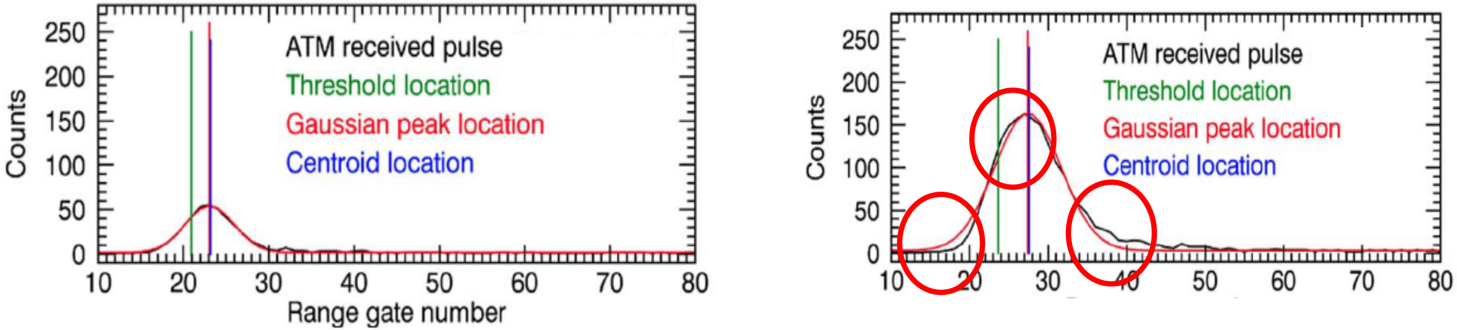


AARI ice charts

	Combination ① ice-water				Combination ② ice-types				Combination ③				Combination ④			
	Overall	FYI	MYI	OW	Overall	FYI	MYI	OW	Overall	FYI	MYI	OW	Overall	FYI	MYI	OW
Accuracy	90.18	78.64	87.63	94.10	89.89	86.35	82.44	92.29	81.74	89.1	69.21	87.35	79.1	89.35	65.63	87.62
STD	0.032	0.07	0.06	0.05	0.05	0.07	0.065	0.06	0.045	0.08	0.05	0.09	0.047	0.045	0.08	0.07

III. Waveform retracking for ice freeboard retrieval

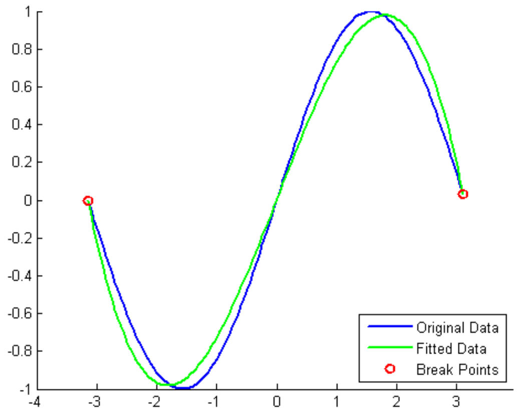
- **<u>Sea ice</u>**: OGOC is a rapid and robust method and has shown a good performance.
- **<u>Open water/lead</u>**: Gauss fitting are the most common retracking methods.
- **<u>Problem</u>**: Gauss fitting need to calculate the statistical parameters and cannot always fit waveform well especially when altimeter footprint cover a small fraction of lead.

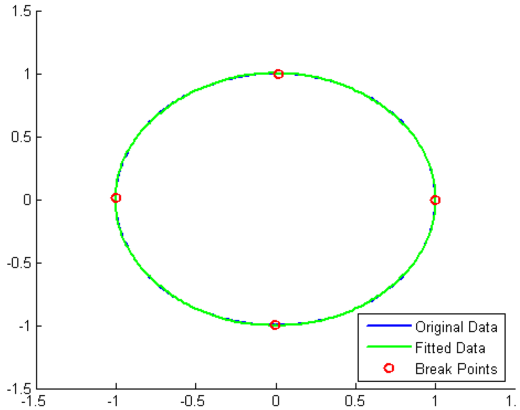


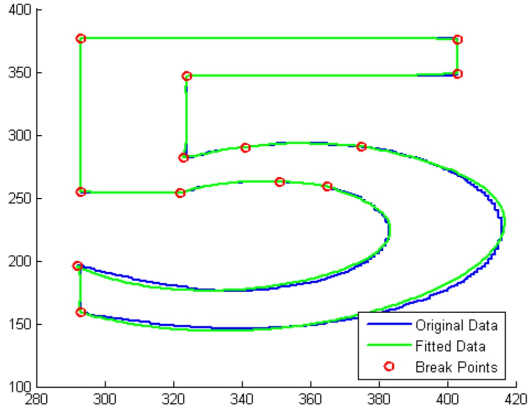
Source: Yi D, et al., 2013.

Bezier curve fitting

- Bezier curve fitting can directly estimates the unknown curve accurately and effectively without assuming any statistical models.
- Bezier curve fitting can fit very complex curve, and has better fitting performance than Gauss fitting.







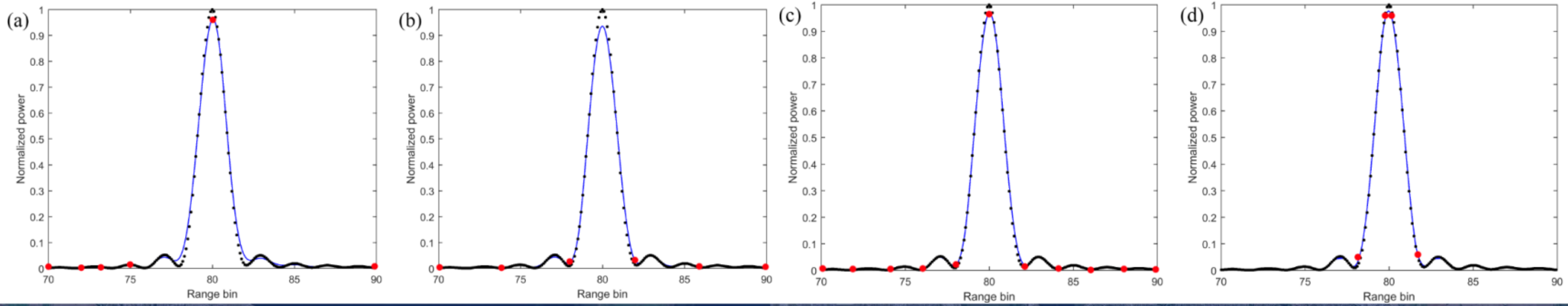
Control points distribution strategy

a) exponential distribution ([0,1/16,1/8,1/4,1/2,1]);

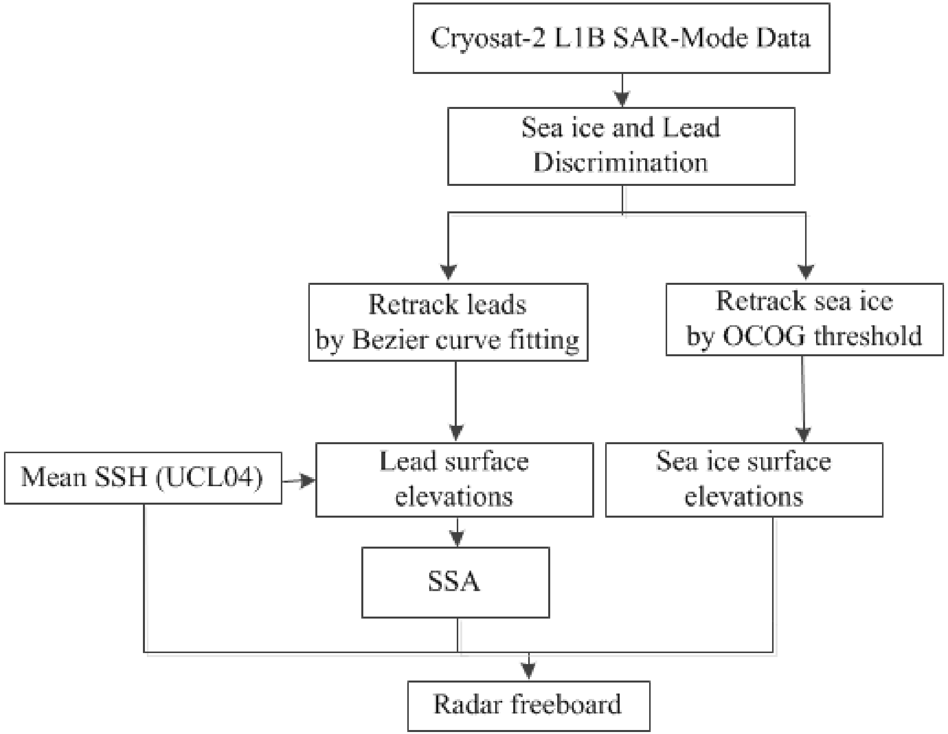
b) uniform distribution ([0, 1/5, 2/5, 3/5, 4/5, 1]);

c) a double sampling density to (b);

d) 4 control points: the 5% of the rising and falling edge; before and after max power (**best performance, less control points and computing time**).



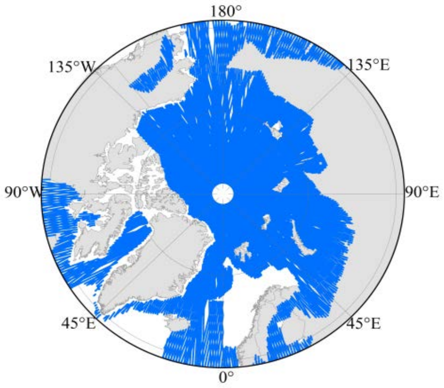
Sea ice freeboard retrieval



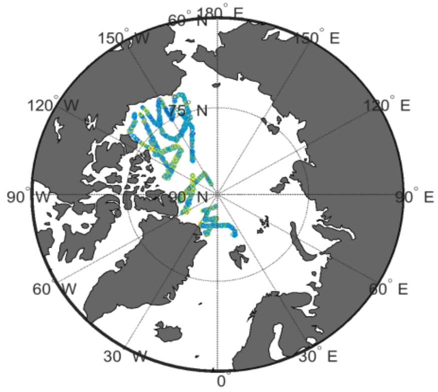
- **Sea ice/Lead/Ocean**: Discrimination by waveform classification.
- **Mean SSH**: mean sea surface height, source: UCL04 model.
- **SSA**: sea surface anomaly, the interpolation of the difference between lead elevations and mean SSH.
- **Radar ice freeboard**: sea ice elevation-mean SSH-SSA.

IV. Validation

- Study area: Arctic
- Test data: Cryosat-2 L1b
- Time coverage: 03/2015 (SAR mode) + 04/2016 (SAR mode)
- Validation data: IceBridge ice freeboard data (Airborne Topographic Mapper)



Cryosat-2 tracks

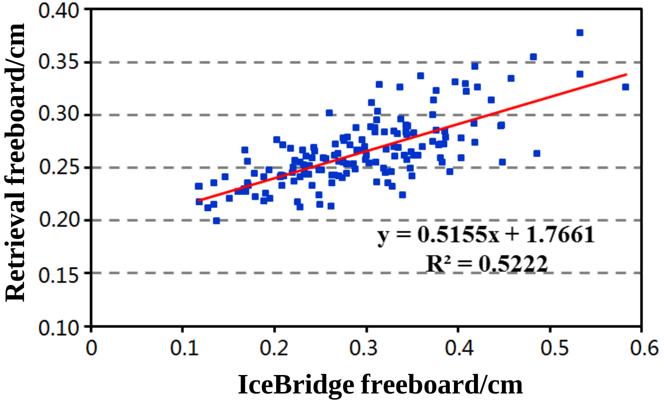


Icebridge tracks

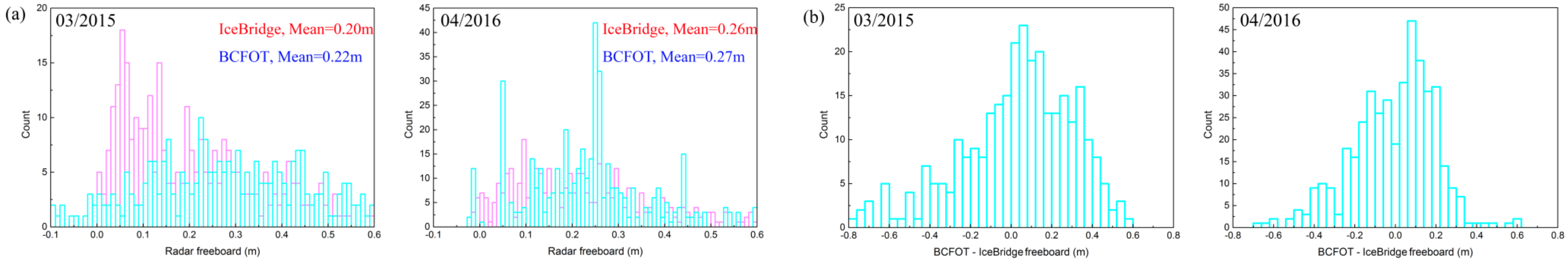
Compared with Cryosat-2 L2I product

- **Proposed method**: mean bias is **1.33 cm** compared with IceBridge freeboard data.
- **Cryosat-2 L2I product**: mean bias is **1.79 cm** compared with IceBridge freeboard data.

	March 2015		April 2016	
Method	Proposed	Production	Proposed	Production
Mean difference	1.57cm	1.75cm	1.09cm	1.84cm
RMS difference	10.7cm	10.5cm	11.5cm	12.7cm



Error analysis



- Retrieved freeboard is higher than IceBridge freeboard.
- Retrieved freeboard shows more uniformly distributed.
- Retrieved freeboard have similar distributions with IceBridge data in April 2016.

V. Conclusions and next planning

- The optimal classifier-feature combinations for ice type classification, and the overall accuracy reaches to 90%.
- The accuracy of proposed sea ice freeboard retrieval algorithm is 1.33 cm compared with IceBridge freeboard data.
- Collection more in-situ data to valid proposed method.
- Study sea ice thickness retrieval algorithm based on retrieved ice-freeboard result.

Thanks for your attention!

Retracking threshold

- Retracking threshold directly connects to the performance of elevation extraction.
- Different thresholds (50%, 70%, 90%) have been compared to decide the optimal threshold for retracker.
- We set the threshold at 70% of peak as it is more accurate than others when compared to IceBridge data.

	March 2015		April 2016	
Thresholds	Radar freeboard	IceBridge freeboard	Radar freeboard	IceBridge freeboard
50%	29.31 cm	20.5 cm	34.77 cm	26.1 cm
70%	22.07 cm		27.19 cm	
90%	14.68 cm		19.43 cm	