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Automatically delineating the calving front of Jakobshavn Isbræ from multitemporal TerraSAR-X images: a deep learning approach

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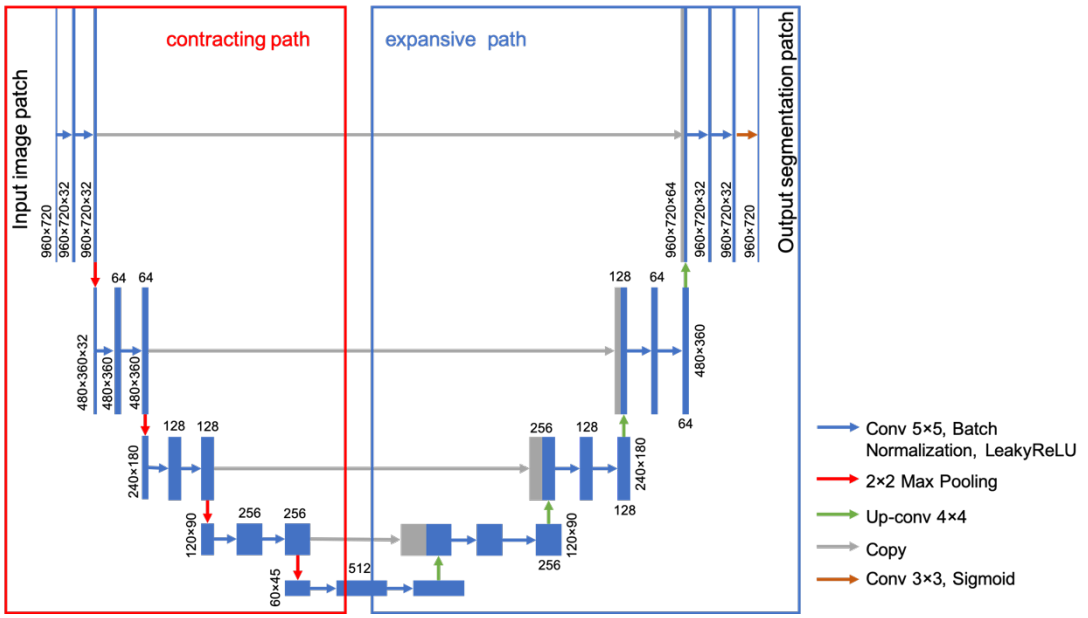

Figure S1. The Architecture of the U-Net. The red box indicates the contracting path and the blue box indicates the expansive path. Each solid blue box corresponds to a multi-channel feature map. Gray solid boxes represent copied feature maps. The length, width, and height of each layer correspond to the pixel dimensions and the number of feature channels respectively. Arrows with different colors denote the different operations.

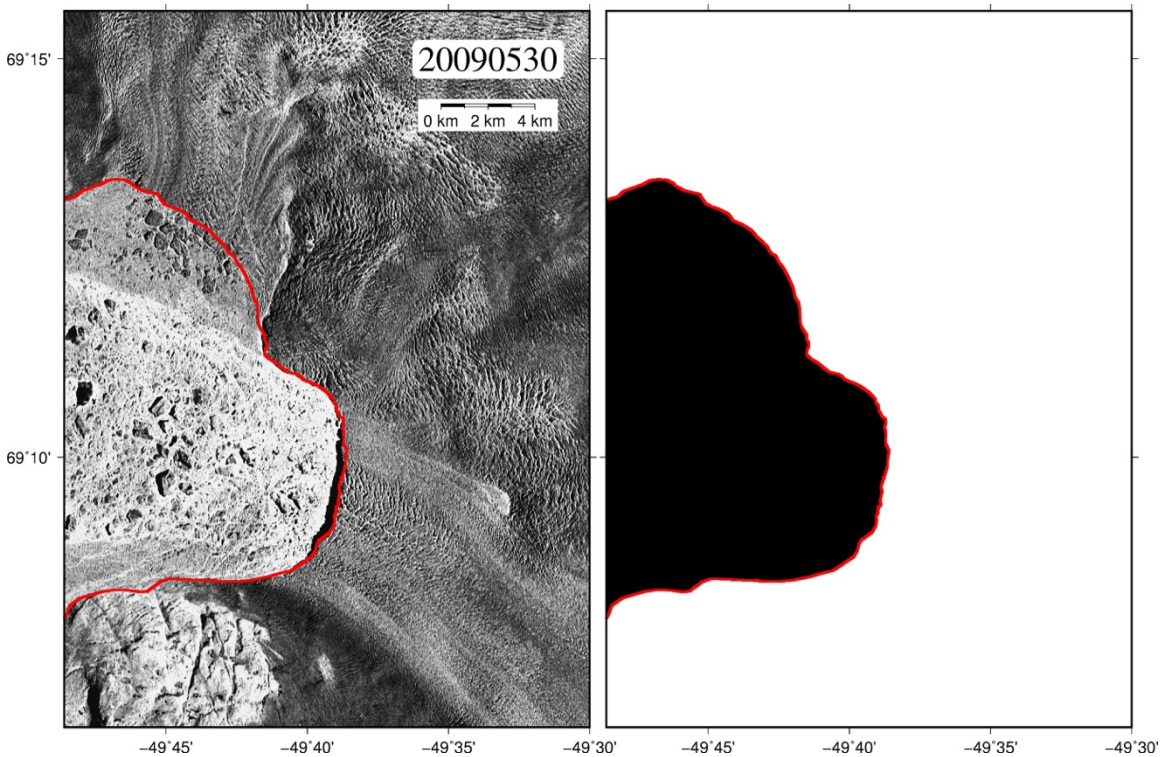

Figure S2. An example of the training dataset. The left is a training image, and the right one is its ground truth image where the black region is ice mélange and the white region is non-ice mélange (including both glacier and bedrock). The red line is the calving front we delineate manually.

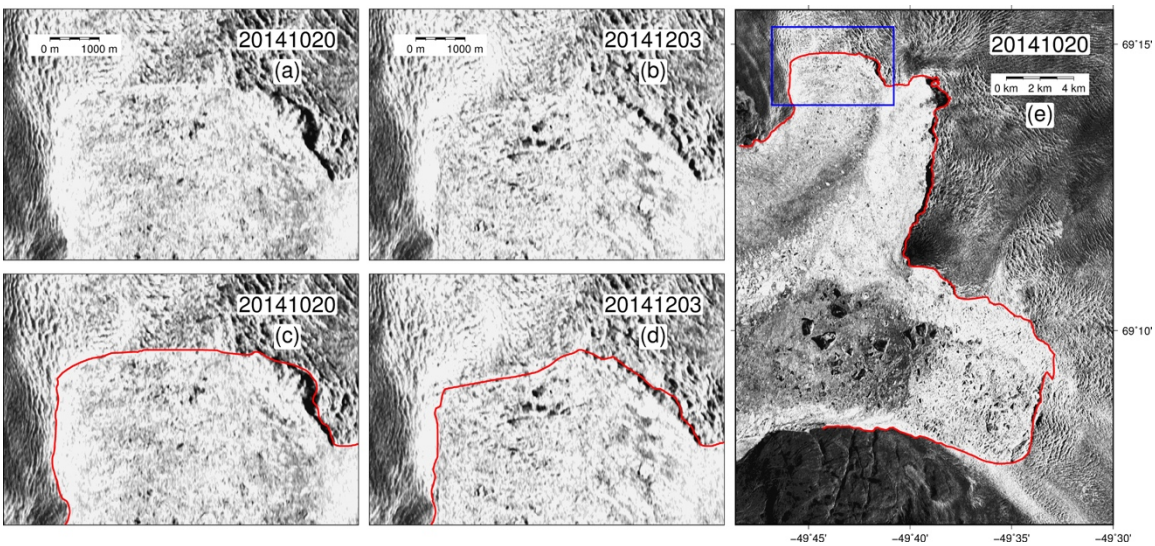

Figure S3. An example showing how we use a reference image to delineate a smooth calving front on a winter image with obscure boundaries. (a) is the reference image and (b) is the image with obscure boundaries. (c) and (d) show the manually delineated calving fronts. The blue box in (e) shows the location of (a)-(d).

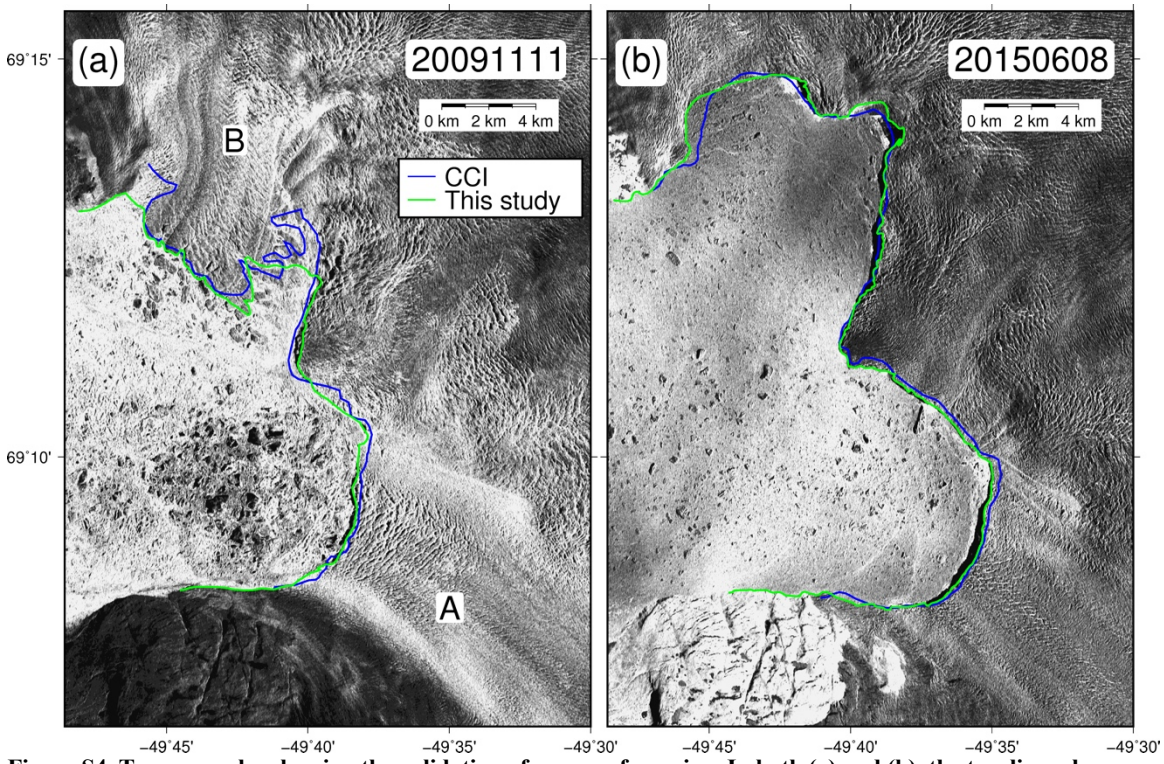

Figure S4. Two examples showing the validation of re-georeferencing. In both (a) and (b), the two lines show the manually delineated calving fronts from ours and the CCI.

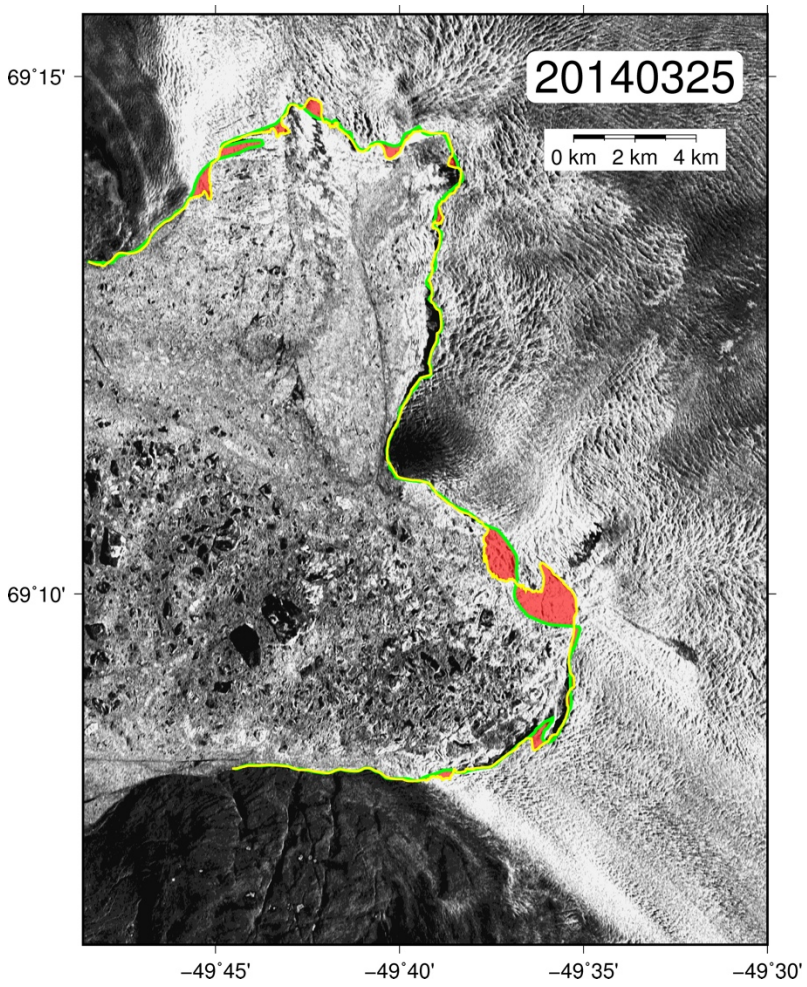

Figure S5. An example of error estimation of the network-delineation. The green line is the calving front we manually delineate. The yellow line is the calving front delineated by the deep-learning network. The red zone indicates the error of our results, which is the area circled by the green and yellow lines.

Movie S1. A movie showing the calving front positions from April 16th, 2009 to December 23rd, 2015. The red curve indicates the calving fronts delineated by our deep learning network.

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Movie S2. A movie showing the calving front variation of Branch A and the cross-section between the calving front and the profile. Two green lines indicate the bed elevation profiles. The red line shows the calving front position.

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Movie S3. Similar to Movie S2 but for Branch B.

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Table S1. List of the TerraSAR-X images used in this study. 'D' and 'A' refer to the descending and ascending orbits, respectively, in the Orbit direction column. The orbit numbers represent the unique ID for each image. We also indicate whether each image is used as a test '0' or train-validation data '1' in the column 'Test/Train'.

Date	Orbit direction	Orbit number	Test/Train	Date	Orbit direction	Orbit number	Test/Train
20090416	D	10192	1	20120911	A	29085	0
20090427	D	10359	1	20120921	D	29230	0
20090508	D	10526	1	20121003	A	29419	1
20090519	D	10693	1	20121014	A	12856	0
20090530	D	10860	1	20121104	D	29898	1
20090610	D	11027	1	20121115	D	30065	0
20090621	D	11194	1	20121207	D	30399	1
20090702	D	11361	0	20121219	A	30588	0
20090713	D	11528	1	20130109	D	30900	1
20090724	D	11695	1	20130120	D	31067	0
20090804	D	11862	0	20130211	D	31401	1
20090815	D	12029	1	20130222	D	31568	0
20090826	D	12196	0	20130306	A	31757	0
20090906	D	12363	0	20130317	A	31924	1
20090917	D	12530	0	20130407	D	32236	0
20090928	D	12697	0	20130418	D	32403	0
20091009	D	12864	0	20130510	D	32737	0
20091020	D	13031	0	20130522	A	32926	1
20091031	D	13198	1	20130613	A	33260	1
20091111	D	13365	0	20130624	A	33427	0
20091122	D	13532	1	20130705	A	33594	1
20091203	D	13699	0	20130727	A	33928	0
20091214	D	13866	1	20130817	D	34240	1
20091225	D	14033	1	20130828	D	34407	0
20100105	D	14200	0	20130908	D	17844	0
20100116	D	14367	1	20130920	A	18033	0
20100207	D	14701	0	20131012	A	18367	0
20100218	D	14868	1	20131023	A	18534	1
20100312	D	15202	1	20131114	A	18868	1
20100323	D	15369	0	20131125	A	19035	0
20100414	D	15703	1	20131206	A	19202	1
20100425	D	15870	0	20131217	A	19369	0
20100506	D	16037	0	20140129	D	36745	1
20100517	D	16204	1	20140303	D	37246	0
20100619	D	16705	1	20140314	D	37413	1
20100630	D	16872	0	20140325	D	37580	0
20100711	D	17039	1	20140405	D	21017	0
20100722	D	17206	1	20140416	D	21184	1
20100904	D	17874	1	20140427	D	38081	0
20100915	D	18041	0	20140610	D	38749	1
20101007	D	1645	1	20140621	D	38916	0
20101018	D	18542	0	20140702	D	39083	0
20101109	D	18876	1	20140703	A	39105	1
20101120	D	19043	0	20140714	A	39272	1
20101201	D	19210	1	20140725	A	39439	1
20101223	D	19544	0	20140804	D	39584	1
20110103	D	19711	1	20140918	A	40274	0
20110125	D	20045	0	20140928	D	40419	1
20110216	D	20379	0	20141009	D	23856	0
20110310	D	20713	0	20141020	D	24023	1
20110321	D	20880	0	20141111	D	41087	1
20110412	D	21214	1	20141203	D	41421	0
20110423	D	21381	0	20141214	D	41588	1
20110515	D	21715	1	20141225	D	41755	0
20110526	D	21882	0	20150105	D	25192	0
20110617	D	22216	0	20150116	D	25359	0
20110720	D	22717	1	20150127	D	42256	1
20110823	A	6510	1	20150207	D	42423	0

20110903	A	23407	1	20150219	A	42612	1
20110914	A	23574	1	20150312	D	26194	1
20111005	D	23886	0	20150323	D	43091	0
20111016	D	24053	0	20150414	D	43425	1
20111108	A	24409	0	20150425	D	43592	0
20111118	D	24554	1	20150506	D	43759	0
20111210	D	24888	0	20150517	D	43926	1
20111221	D	25055	0	20150608	D	44260	0
20120113	A	24409	1	20150619	D	44427	0
20120123	D	25556	1	20150711	D	44761	0
20120214	D	25890	0	20150722	D	44928	1
20120225	D	26057	0	20150802	D	45095	0
20120307	D	26224	0	20150813	D	45262	0
20120329	D	26558	1	20150904	D	45596	0
20120420	D	26892	1	20150926	D	45930	1
20120524	12	27415	1	20151018	D	46264	0
20120603	D	27560	0	20151029	D	46431	0
20120614	D	27727	0	20151109	D	46598	1
20120707	12	28083	1	20151120	D	46765	0
20120718	12	11520	1	20151212	D	47099	1
20120809	12	11854	1	20151223	D	47266	0
20120820	12	28751	0				

Table S2. List of the geocoding difference between our results and the CCI products in terms of equivalent lengths, and the manual delineation error measured by comparing two sets of independent delineation results.

Date (yyyymmdd)	20091111	20100506	20110617	20140703	20140928	20150608	Mean
Geocoding Difference (m)	167	95	77	84	115	87	104 (~17.3 pixels)
Manual Delineation Error(m)	40	71	12	22	34	18	33 (~5.5 pixels)

Table S3. Test error of each image and their means.

Date	Error (m)	Date	Error (m)	Date	Error (m)
20090702	26	20111221	48	20140427	72
20090804	20	20120214	57	20140621	19
20090906	20	20120225	27	20140702	38
20090928	50	20120307	23	20140714	29
20091009	66	20120614	20	20140725	14
20091020	52	20120707	20	20140918	32
20091111	34	20120820	15	20141009	27
20091203	25	20120911	24	20141203	24
20100105	38	20120921	38	20141225	31
20100207	58	20121014	52	20150105	35
20100323	65	20121115	34	20150116	31
20100425	56	20121219	63	20150207	35
20100506	57	20130120	59	20150323	42
20100630	58	20130222	57	20150425	30
20100915	12	20130306	58	20150506	48
20101018	31	20130407	37	20150608	12
20101120	42	20130418	32	20150619	22
20101223	28	20130510	23	20150711	23
20110125	21	20130624	39	20150802	20
20110216	43	20130727	55	20150813	67
20110310	22	20130828	32	20150904	45
20110423	102	20130908	24	20151018	28
20110526	61	20130920	34	20151029	48
20110617	31	20131012	30	20151120	38

20110903	19	20131125	19	20151223	32
20111005	26	20131217	51		
20111016	24	20140303	49	Total Mean	38 (6 pixels)
20111108	67	20140325	74	Summer Mean	31 (5 pixels)
20111210	35	20140405	38	Winter mean	42 (7 pixels)