Supplement of Calving Front Machine (CALFIN): Automated Calving Front Dataset and Deep Learning Methodology for East/West Greenland, 1972-2019

Daniel Cheng[1], Wayne Hayes[1], Eric Larour[2], Yara Mohajerani[1,3], Michael Wood[2], Isabella Velicogna[1,2], and Eric Rignot[1,2]

[1]University of California at Irvine, Irvine CA, USA
[2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, USA
[3]University of Washington, eScience Institute and Department of Civil and Environmental Engineering, Seattle, WA, 98195, USA

Correspondence: Daniel Cheng (dlcheng@uci.edu)

Contents

1 Temporal Availability **2**

2 Inter-model Comparison Table **3**

3 Dataset Metadata **3**

4 Error Estimation **5**

5 Training Data **6**

6 Validation Data **7**

6.1 CALFIN Validation Set 7

6.2 Mohajerani et al. Validation Set 10

6.3 Zhang et al. Validation Set 11

6.4 Baumhoer et al. Validation Set 11

7 Helheim Relative Length Change, CAFLIN vs ESA-CCI, 1995-2016 **13**

8 CALFIN Validation Set Scene ID List **14**

1 Temporal Availability

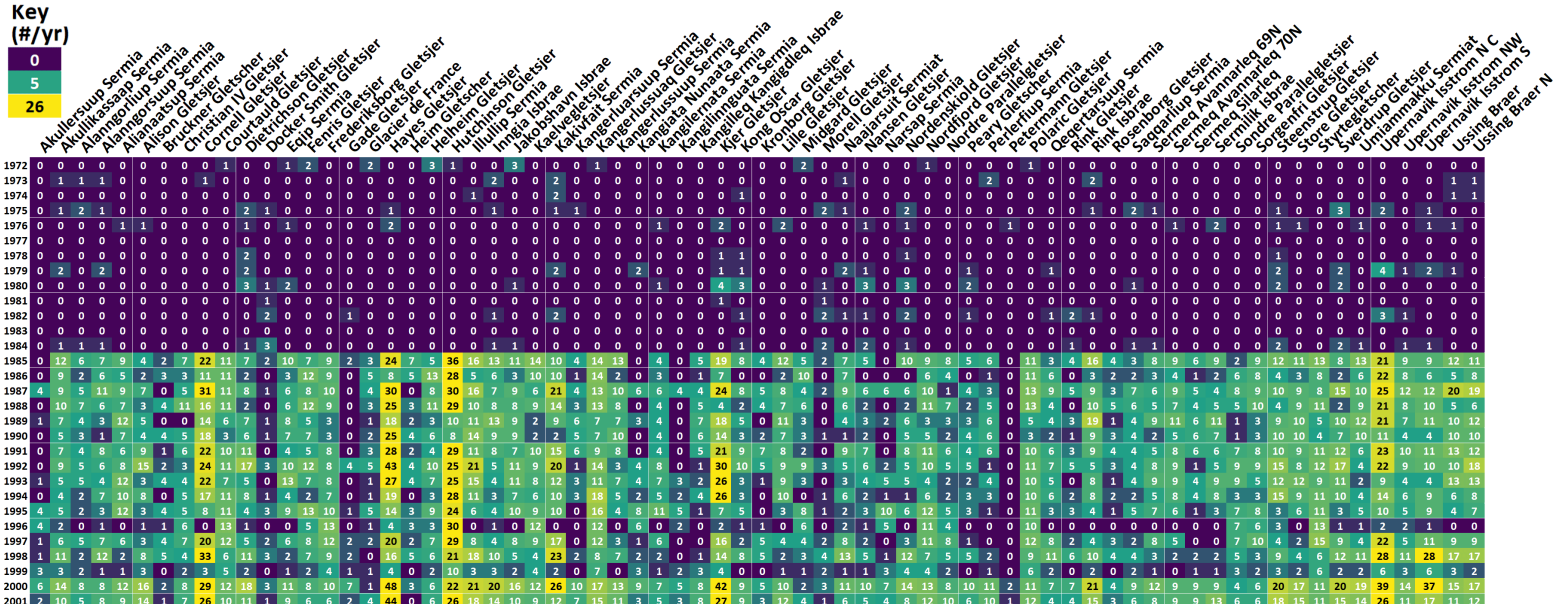

Figure S1. Temporal Availability Chart. Listed are the number of fronts per year, for all 66 glaciers in the CALFIN dataset.

2 Inter-model Comparison Table

Table S1. Consolidated validation set and inter-model error metrics.

Validation Set	Model	Mean Distance	Median Distance	IoU Coastline	IoU Ice/Ocean
CALFIN-VS	CALFIN-NN	2.25 px, 86.76 m	1.21 px, 44.59 m	0.4884	0.9793
CALFIN-VS-L7-none	CALFIN-NN	2.27 px, 81.65 m	1.16 px, 44.01 m	0.4880	0.9819
CALFIN-VS-L7-only	CALFIN-NN	2.22 px, 91.93 m	1.33 px, 49.24 m	0.4888	0.9766
M-VS	CALFIN-NN	2.56 px, 97.72 m	2.55 px, 97.44 m	0.3332	N/A
M-VS	M-NN	1.97 px, 96.31 m	N/A	N/A	N/A
Z-VS	CALFIN-NN	2.11 px, 115.24 m	1.65 px, 77.29 m	0.3832	0.9761
Z-VS	Z-NN	17.3 px, 104 m	N/A	N/A	N/A
B-VS	CALFIN-NN	2.35 px, 330.63 m	0.74 px, 112.75 m	0.6451	0.9879
B-VS	B-NN	2.69 px, 108 m	N/A	N/A	0.905

3 Dataset Metadata

Level 0 products consist of fjord boundary GeoTiff masks, the domain Shapefiles used for subsetting, and the Landsat scene name list text files. Level 1 product consists of a LineString Shapefile with 22678 features, and a Polygon Shapefile with 17771 features, grouped by glacial basin. Both Shapefiles share a feature schema derived from the MEaSUREs glacial terminus positions dataset (NSIDC-0642), as detailed in Table S2.

- Temporal resolution: sub-seasonal
- Spatial resolution: ~30 meters
- Spatial accuracy: <90 meters
- Projection: EPSG:3413 (WGS 84 / NSIDC Sea Ice Polar Stereographic North)

Table S2. Shapefile Feature Schema Attribute Table

Data Field	Description	Format (Values)
GlacierID	Numerical ID assigned to each glacier (as derived from MEaSUREs NSIDC-0642)	# ([1, 246])
Center_X	Mean X coordinate in EPSG:3413.	# ([-463626, 682313])
Center_Y	Mean Y coordinate in EPSG:3413.	# ([-2821269, -906747])
Latitude	Latitude of center.	# ([64.29, 81.24])
Longitude	Longitude of center.	# ([-63.17, -28.21])
QualFlag	Quality flag to indicate digitization conditions	# (0 – Manually digitized, 3 – Manually digitized, w/ L7 SCE, 10 - Automatically digitized, 13 – Automatically digitized, w/ L7 SCE. See MEaSUREs NSIDC-0642)
Sattellite	Satellite/sensor of the digitized source image	LXSS ([LM01, LC08]) See https://www.usgs.gov/faqs/what-naming-convention-landsat-collections-level-1-scenes
Date	Date of the digitized source image	YYYY-MM-DD ([1972-09-06, 2019-06-25])
ImageID	Source image file name.	LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CC_TX (LC08_L1TP_026006_20170702_20170715_01_T1, etc.)
GrnlndcN	Greenlandic glacier name	NAME (New_Greenl names from Bjørk et al., 2015 database of Greenland glacier names)
OfficialN	Officially recognized glacier name	NAME (Official_n names from Bjørk et al., 2015 database of Greenland glacier names)
AltName	Alternative, Foreign, Old Greenlandic, or other glacier names	NAME (Foreign_na, Old_Greenl, Alternative names (Bjørk et al., 2015), or other names)
RefName	Reference glacier name, non-authoritative names used in CALFIN to denote grouped/unnamed glaciers	NAME (New_Greenl, Official_n, Foreign_na, Old_Greenl, Alternative names (Bjørk et al., 2015), or other names)
Author	Digitization author's name	LastName_FirstInitial (Cheng_D)

4 Error Estimation

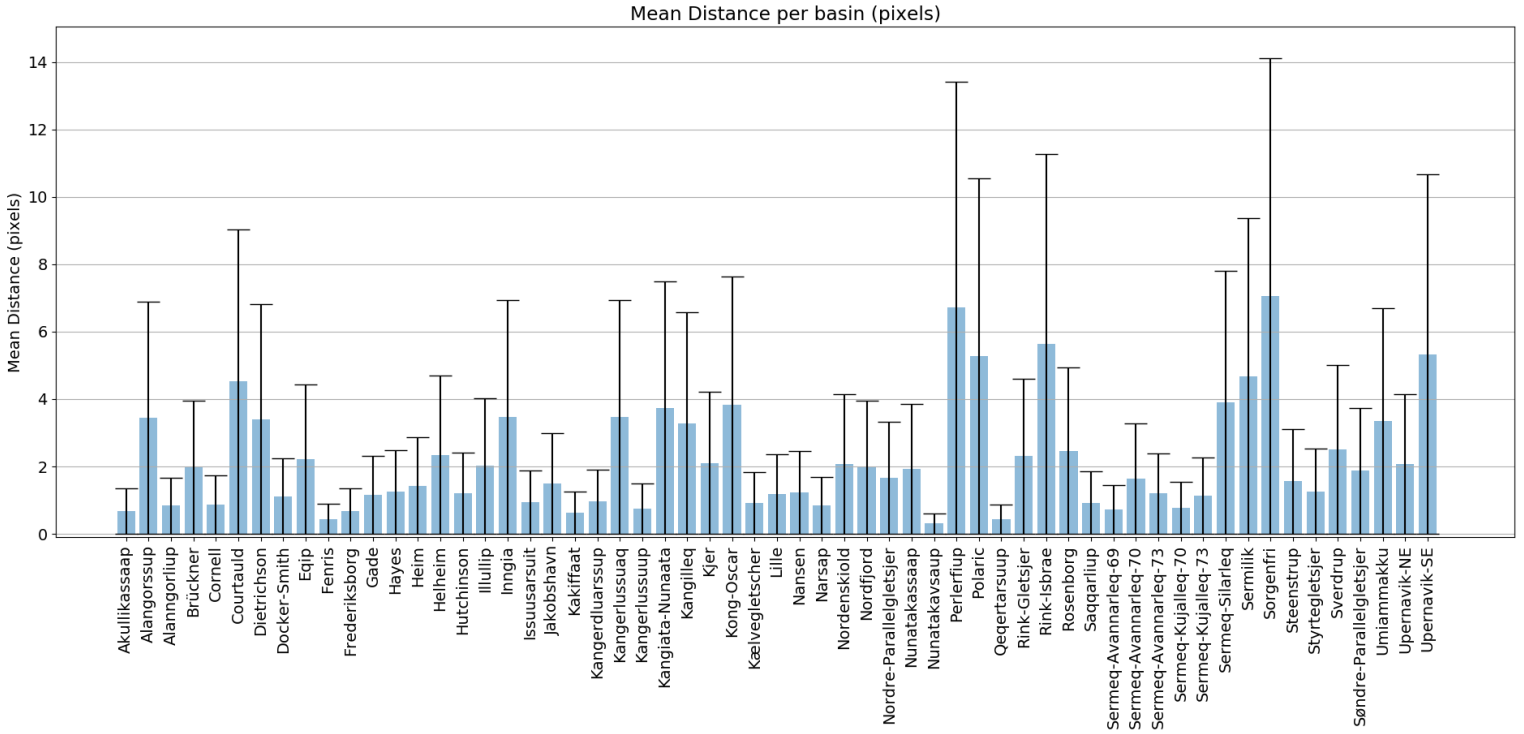

Figure S2. True mean distance error estimates per basin, in pixels. We estimate the true mean distance error per basin to lie between the above intervals with 95% confidence.

5 Training Data

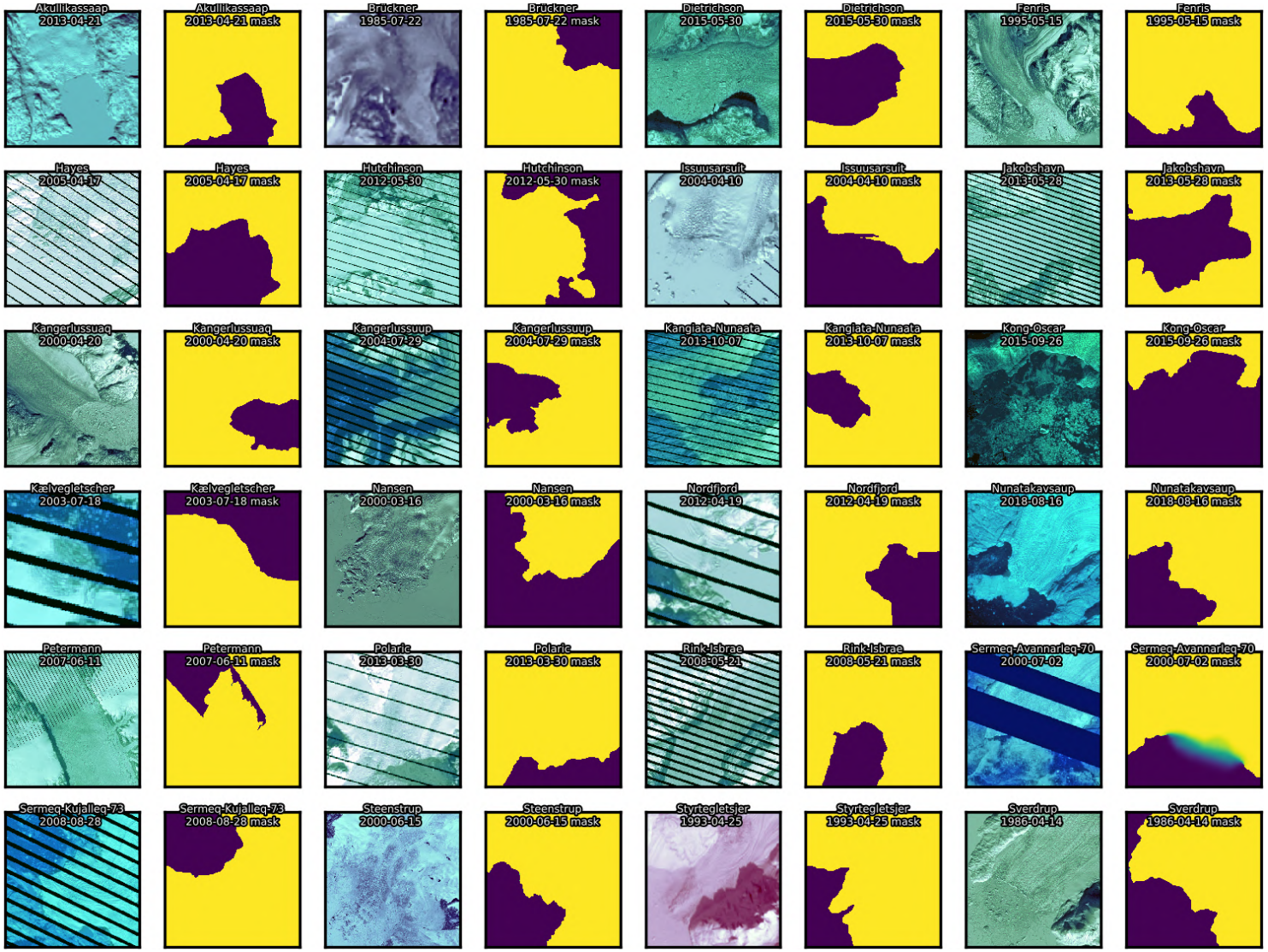

Figure S3. CALFIN-NN training data. Show above is a subset of the 1872 CALFIN-NN training image/mask pairs. Not shown are the coastline masks, which are dynamically generated after performing data augmentation on the above masks, using Canny edge filters and dilation to a 3 pixel wide edge. Note blurred mask in uncertain areas, as in Sermeq Avannarleq 70 2000-07-02. Images are masked at a minimum resolution of 1024 pixels.

6 Validation Data

6.1 CALFIN Validation Set

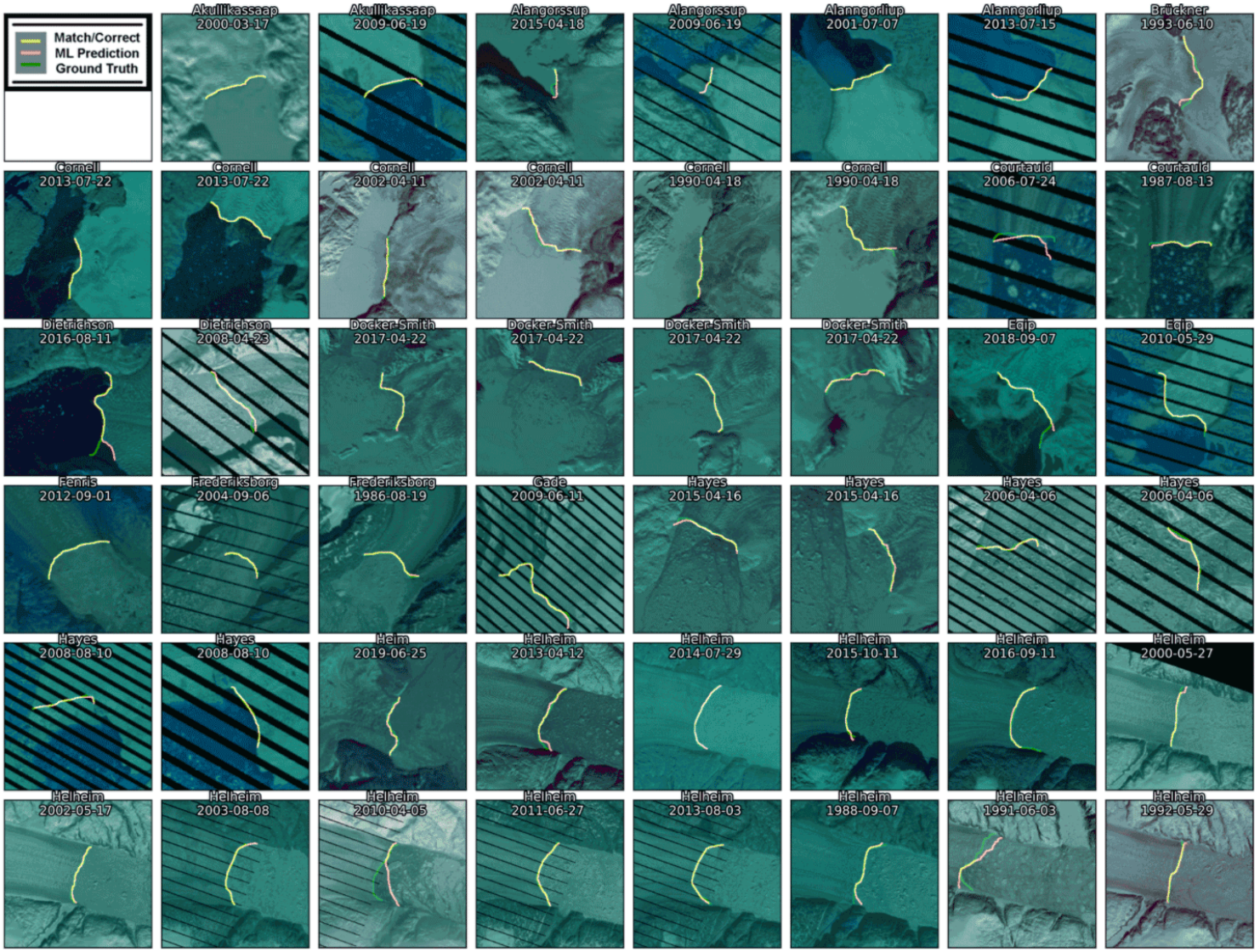

Figure S4. CALFIN validation outputs, part 1.

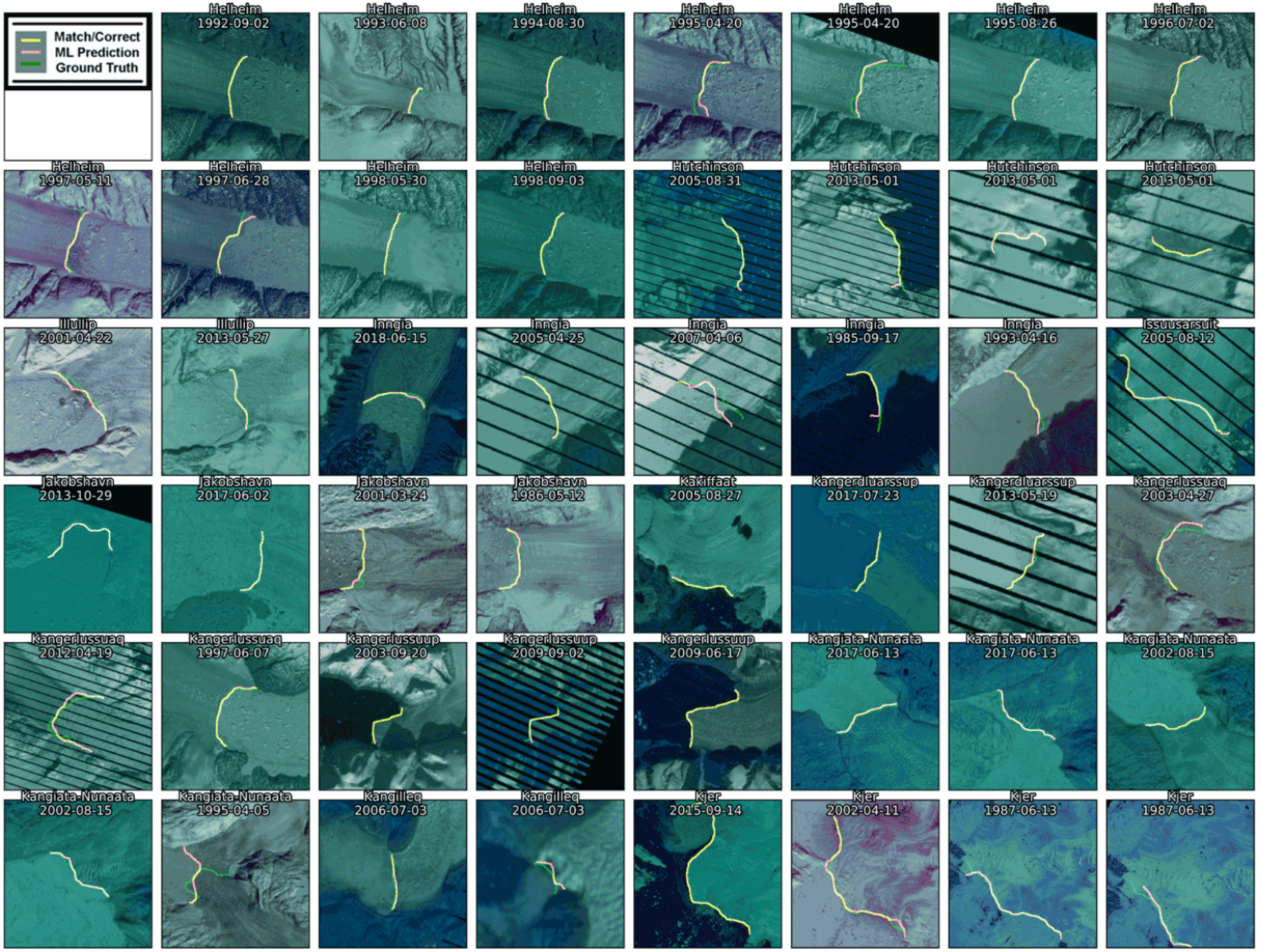

Figure S5. CALFIN validation outputs, part 2.

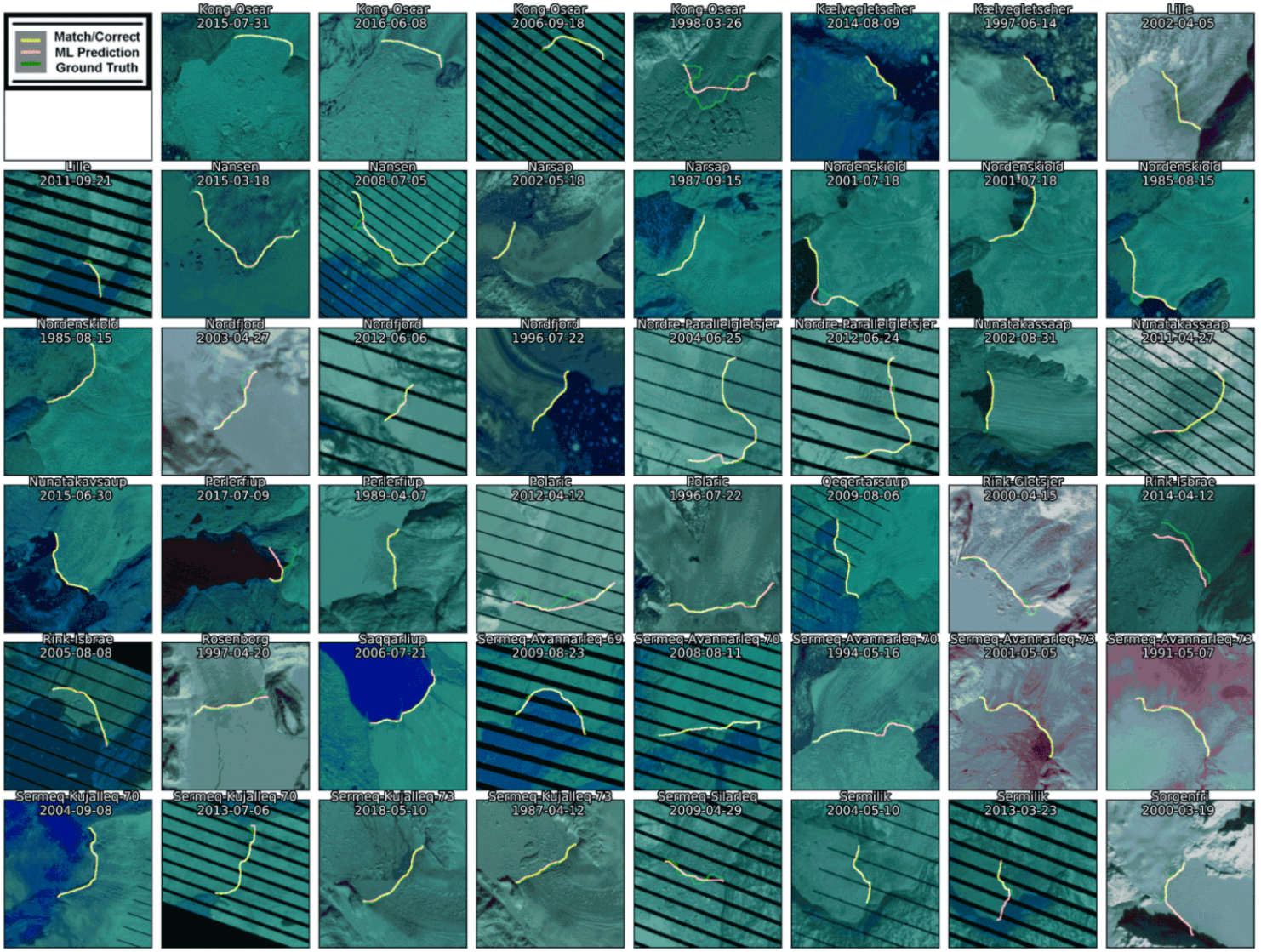

Figure S6. CALFIN validation outputs, part 3.

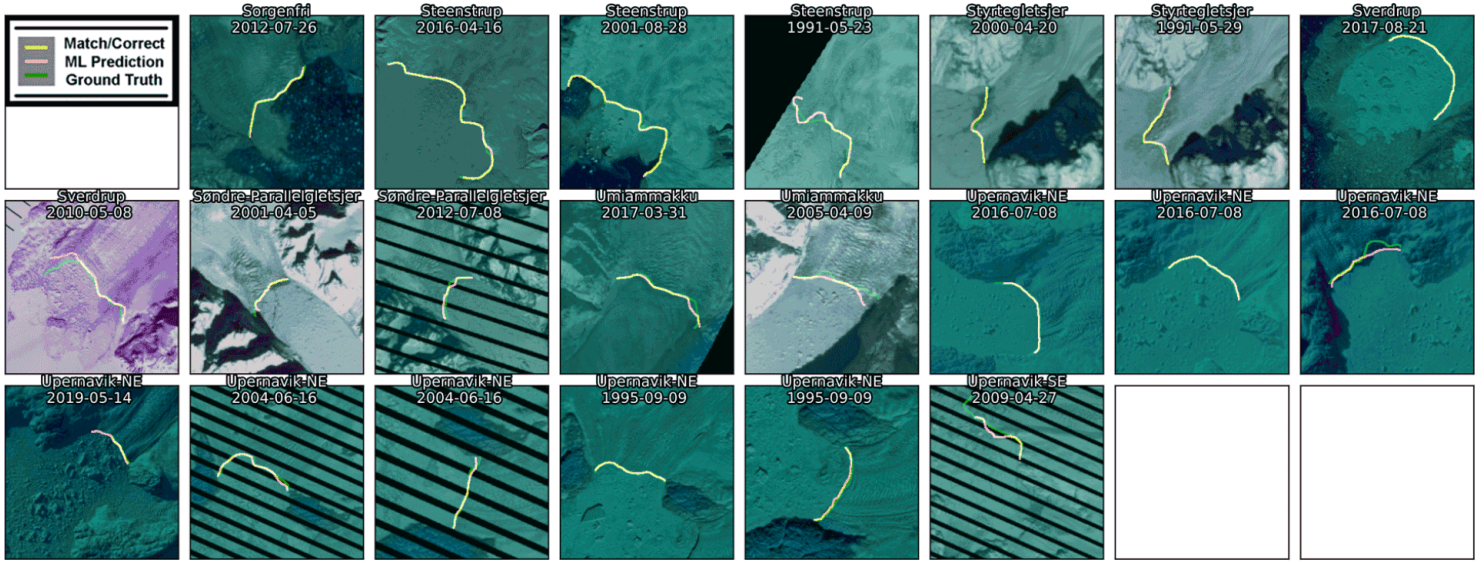

Figure S7. CALFIN validation outputs, part 4.

6.2 Mohajerani et al. Validation Set

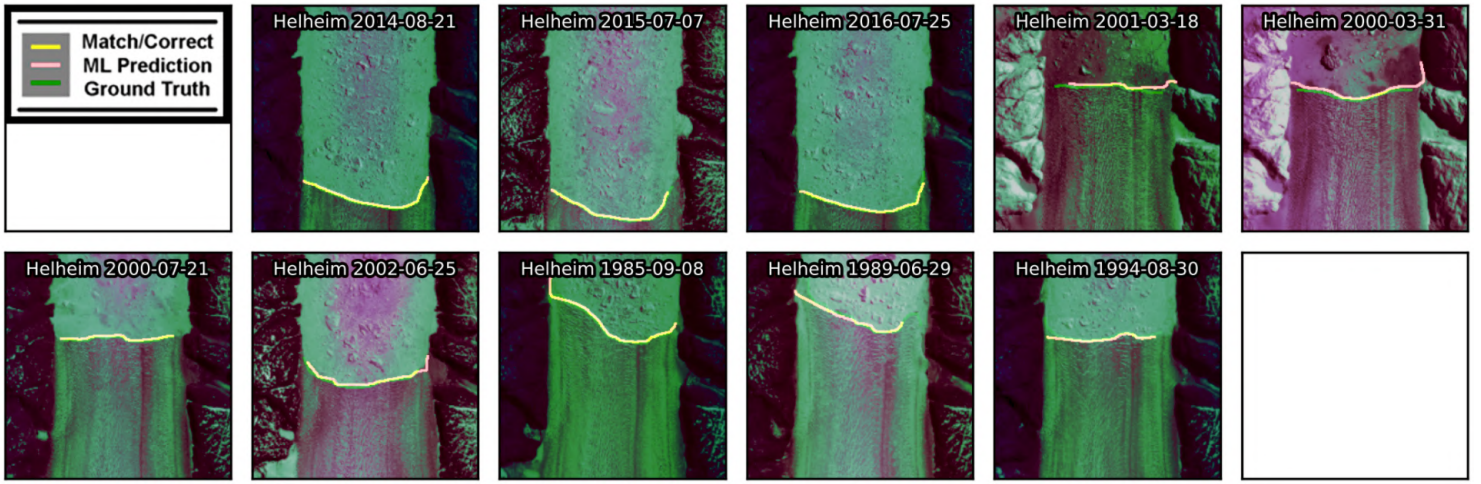

Figure S8. Mohajerani et al. validation outputs.

6.3 Zhang et al. Validation Set

Figure S9. Zhang et al. validation outputs. Note that there are missing subsets where CALFIN did not detect any fronts, despite them being visible.

6.4 Baumhoer et al. Validation Set

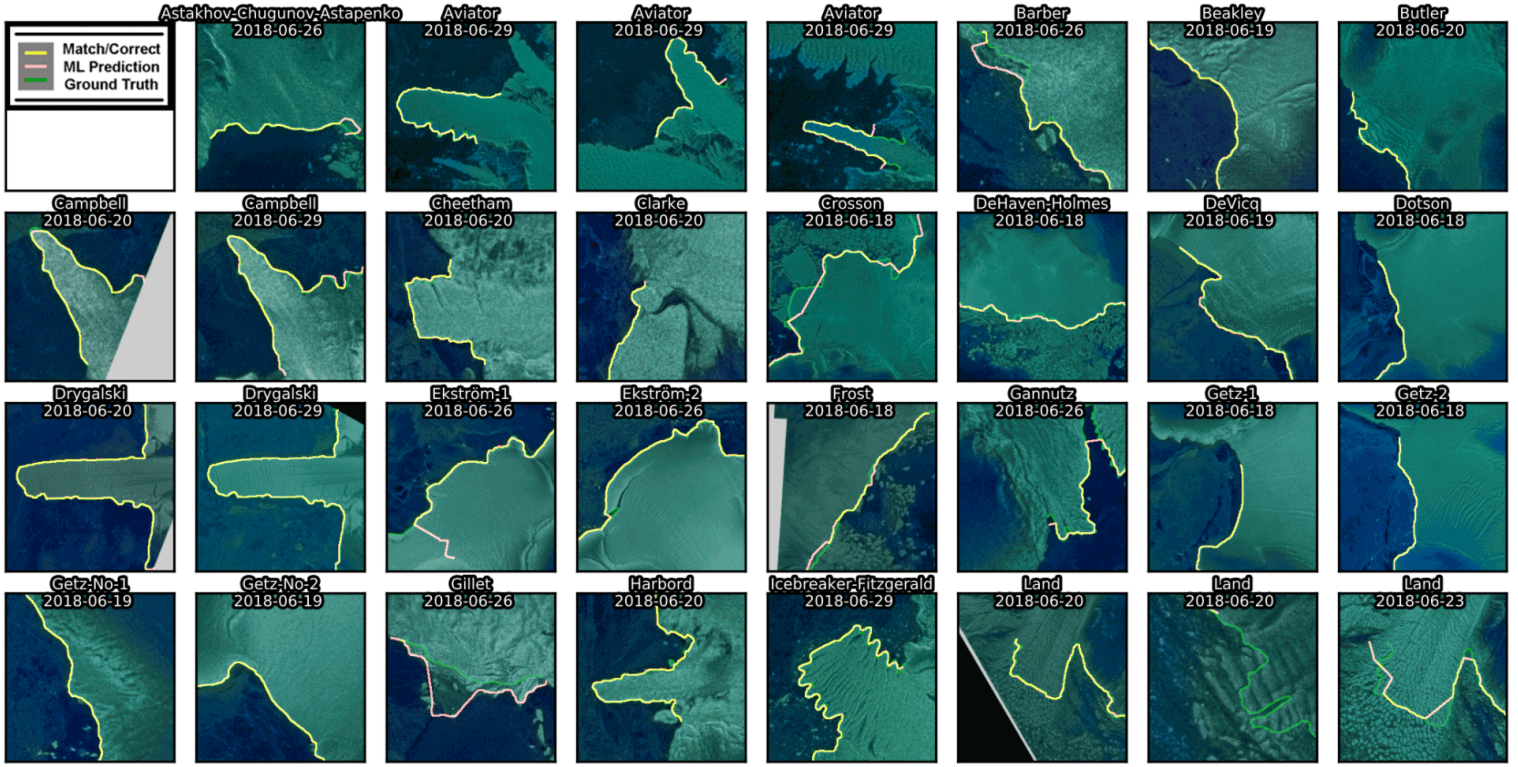

Figure S10. Baumhoer et al. validation outputs, part 1. Large errors originate from Ekstrom-1, Gillet, Land, and other similar domains.

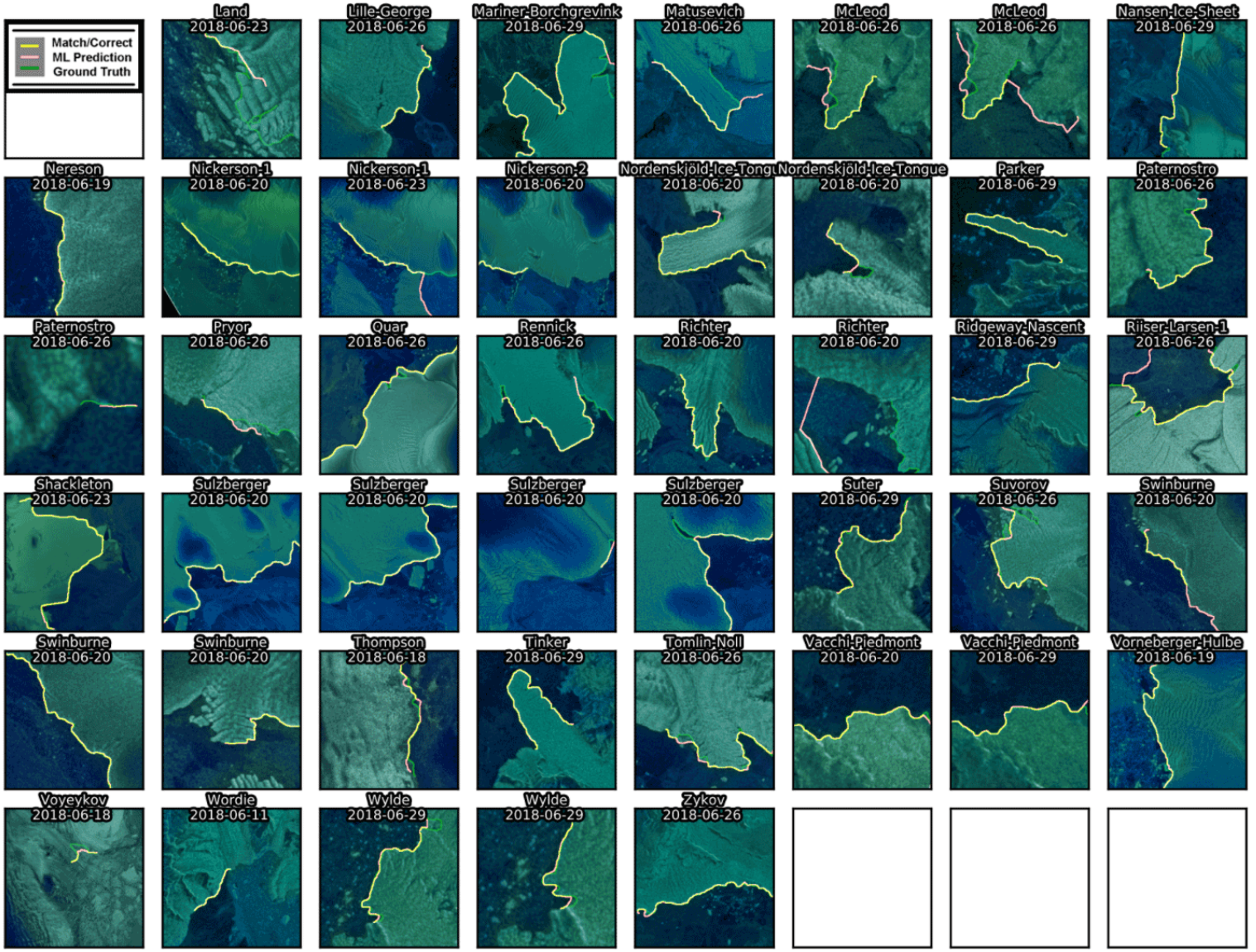

Figure S11. Baumhoer et al. validation outputs, part 2. Note that Wordie and Voyeykov, among others, have not been fully nor confidently detected.

7 Helheim Relative Length Change, CAFLIN vs ESA-CCI, 1995-2016

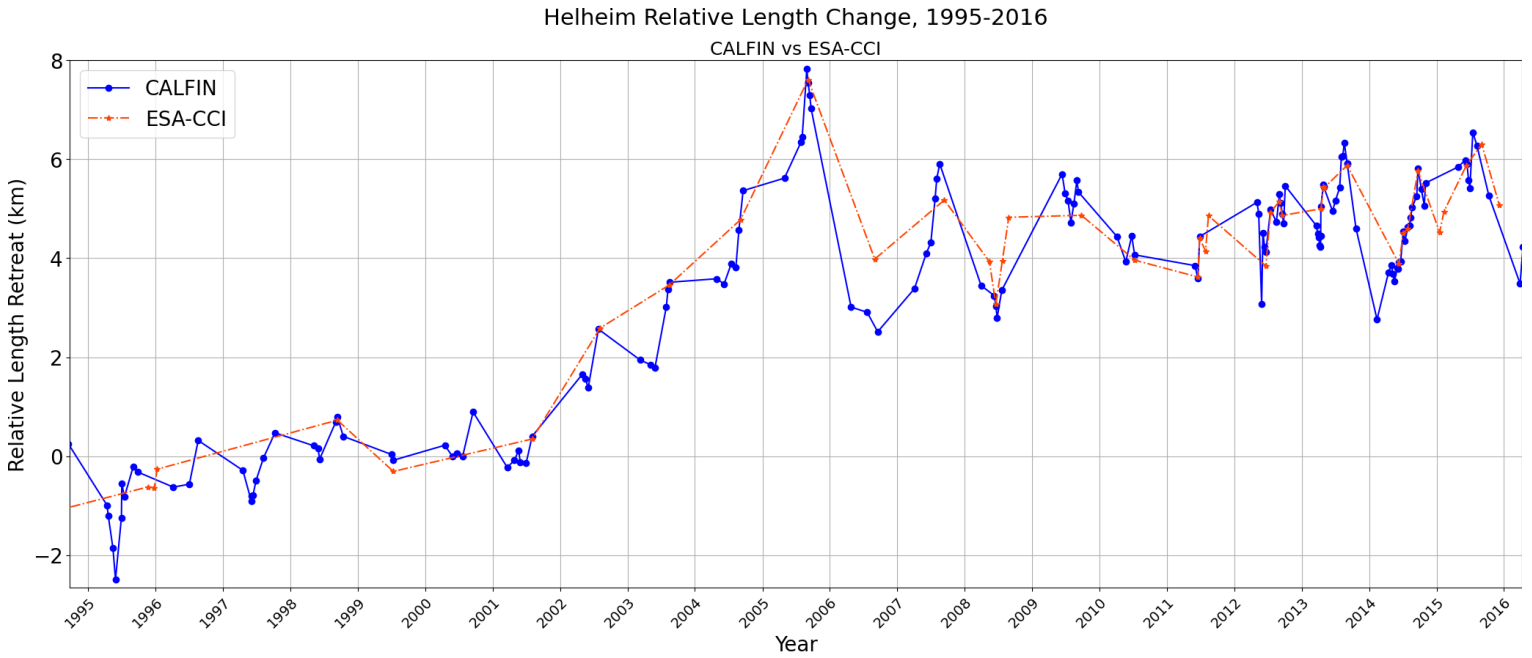

Figure S12. Helheim 1995-2016 terminus length change as measured by CALFIN vs ESA-CCI. Positive length change represents retreat relative to the 1972 position. Note a small number of exact matches, along with the general agreement in both seasonal as well as overall trends.

8 CALFIN Validation Set Scene ID List

Table S3: **CALFIN Validation Set Scene ID List**. A list of all 162 images used in the CALFIN-VS.

Domain	Scene ID	Domain	Scene ID
Akullikassaap	LE07_L1TP_014009_20000317_20170212_01_T1	Akullikassaap	LE07_L1TP_017008_20090619_20161221_01_T1
Alangorssup	LC08_L1TP_016008_20150418_20170409_01_T1	Alangorssup	LE07_L1TP_017008_20090619_20161221_01_T1
Alanngorliup	LE07_L1TP_009011_20010707_20170204_01_T1	Alanngorliup	LE07_L1TP_010011_20130715_20161123_01_T1
Brückner	LT05_L1TP_231014_19930610_20180228_01_T2	Cornell	LC08_L1TP_019007_20130722_20170503_01_T1
Cornell	LE07_L1TP_019007_20020411_20170131_01_T1	Cornell	LT05_L1TP_019007_19900418_20170130_01_T1
Courtauld	LE07_L1TP_231012_20060724_20170109_01_T1	Courtauld	LT05_L1TP_231012_19870813_20170211_01_T1
Dietrichson	LC08_L1TP_023006_20160811_20170322_01_T1	Dietrichson	LE07_L1TP_023006_20080423_20161229_01_T1
Docker-Smith	LC08_L1TP_025006_20170422_20170501_01_T1	Eqip	LC08_L1TP_010011_20180907_20180912_01_T1
Eqip	LE07_L1TP_009011_20100529_20161215_01_T1	Fenris	LE07_L1TP_232013_20120901_20161128_01_T1
Frederiksborg	LE07_L1TP_229012_20040906_20170119_01_T1	Frederiksborg	LT05_L1TP_230012_19860819_20170216_01_T1
Gade	LE07_L1TP_025006_20090611_20161219_01_T1	Hayes	LC08_L1TP_018007_20150416_20170409_01_T1
Hayes	LC08_L1TP_080237_20160607_20170324_01_T1	Hayes	LE07_L1TP_019007_20060406_20170110_01_T1
Hayes	LE07_L1TP_018007_20080810_20161225_01_T1	Heim	LC08_L1TP_232014_20190625_20190625_01_RT
Helheim	LC08_L1TP_233013_20130412_20170505_01_T1	Helheim	LC08_L1TP_232014_20140729_20170420_01_T1
Helheim	LC08_L1TP_233013_20151011_20170403_01_T1	Helheim	LC08_L1TP_233013_20160911_20170321_01_T1
Helheim	LC08_L1TP_232013_20180606_20180615_01_T1	Helheim	LE07_L1TP_232014_20000527_20170211_01_T1
Helheim	LE07_L1TP_232013_20020517_20170130_01_T1	Helheim	LE07_L1TP_232013_20030808_20170124_01_T1
Helheim	LE07_L1TP_232013_20060512_20170109_01_T2	Helheim	LE07_L1TP_232013_20100405_20161215_01_T2
Helheim	LE07_L1TP_232013_20110627_20161208_01_T1	Helheim	LE07_L1TP_232013_20130803_20161123_01_T1
Helheim	LT05_L1TP_232014_19860817_20170216_01_T1	Helheim	LT05_L1TP_232013_19880907_20170206_01_T1
Helheim	LT05_L1TP_233013_19910603_20180228_01_T2	Helheim	LT05_L1TP_232013_19910714_20180228_01_T1
Helheim	LT05_L1TP_232013_19920529_20180228_01_T2	Helheim	LT05_L1TP_232013_19920614_20180228_01_T2
Helheim	LT05_L1TP_232013_19920902_20180228_01_T1	Helheim	LT05_L1TP_232014_19930430_20180228_01_T2
Helheim	LT05_L1TP_233013_19930608_20180228_01_T2	Helheim	LT05_L1TP_233013_19940830_20170113_01_T2
Helheim	LT05_L1TP_232013_19950420_20180228_01_T2	Helheim	LT05_L1TP_232014_19950420_20180228_01_T2
Helheim	LT05_L1TP_232014_19950826_20180228_01_T1	Helheim	LT05_L1TP_233013_19960702_20180228_01_T1
Helheim	LT05_L1TP_232013_19970511_20180228_01_T2	Helheim	LT05_L1TP_232013_19970628_20180228_01_T1

Continued on next page

Table S3 – *Continued from previous page*

Domain	Scene ID	Domain	Scene ID
Helheim	LT05_L1TP_232013_19980530_20161224_01_T1	Helheim	LT05_L1TP_232013_19980903_20161222_01_T1
Hutchinson	LE07_L1TP_230012_20050831_20170114_01_T1	Hutchinson	LE07_L1TP_230012_20130501_20161124_01_T2
Illullip	LE07_L1TP_021007_20010422_20170206_01_T1	Illullip	LE07_L1TP_019007_20130527_20161124_01_T1
Inngia	LC08_L1TP_014009_20180615_20180703_01_T1	Inngia	LE07_L1TP_013009_20050425_20170115_01_T1
Inngia	LE07_L1TP_014009_20070406_20170104_01_T1	Inngia	LT05_L1TP_013009_19850917_20170218_01_T1
Inngia	LT05_L1TP_013009_19930416_20180220_01_T1	Issuusarsuit	LE07_L1TP_024006_20050812_20170113_01_T1
Jakobshavn	LC08_L1TP_008012_20131029_20170429_01_T1	Jakobshavn	LC08_L1TP_008012_20170602_20170615_01_T1
Jakobshavn	LE07_L1TP_010011_20010324_20170206_01_T1	Jakobshavn	LT05_L1TP_008011_19860512_20170218_01_T1
Jakobshavn	LT05_L1TP_008011_19950505_20180220_01_T1	Kakiffaat	LE07_L1TP_017008_20050827_20170114_01_T1
Kangerdluarssup	LC08_L1TP_013009_20170723_20170809_01_T1	Kangerdluarssup	LE07_L1TP_011010_20130519_20161124_01_T1
Kangerlussuaq	LE07_L1TP_231012_20030427_20170125_01_T2	Kangerlussuaq	LE07_L1TP_231012_20120419_20161202_01_T2
Kangerlussuaq	LT05_L1TP_229012_19970607_20180227_01_T1	Kangerlussuup	LE07_L1TP_012010_20030920_20170124_01_T1
Kangerlussuup	LE07_L1TP_014009_20090902_20161220_01_T1	Kangerlussuup	LT05_L1TP_011010_20090617_20161025_01_T1
Kangiata-Nunaata	LC08_L1TP_005015_20170613_20170628_01_T1	Kangiata-Nunaata	LE07_L1TP_005015_20020815_20170128_01_T1
Kangiata-Nunaata	LT05_L1TP_006015_19950405_20170109_01_T1	Kangilleq	LE07_L1TP_011010_20060703_20170109_01_T1
Kjer	LC08_L1TP_019007_20150914_20170404_01_T1	Kjer	LE07_L1TP_019007_20020411_20170131_01_T1
Kjer	LT05_L1TP_019007_19870613_20170212_01_T1	Kong-Oscar	LC08_L1TP_024006_20150731_20170406_01_T1
Kong-Oscar	LC08_L1TP_023006_20160608_20170324_01_T1	Kong-Oscar	LE07_L1TP_022006_20060918_20170107_01_T1
Kong-Oscar	LT05_L1TP_024006_19980326_20161225_01_T1	Kælvegletscher	LC08_L1TP_229012_20140809_20170420_01_T1
Kælvegletscher	LE07_L1TP_231012_20050603_20170114_01_T2	Kælvegletscher	LE07_L1TP_231012_20120825_20161129_01_T1
Kælvegletscher	LT05_L1TP_230012_19970614_20180227_01_T1	Lille	LE07_L1TP_009011_20020405_20170131_01_T1
Lille	LE07_L1TP_009011_20110921_20161206_01_T1	Midgård	LT05_L1TP_232013_19950927_20180228_01_T1
Nansen	LC08_L1TP_023006_20150318_20170412_01_T1	Nansen	LE07_L1TP_022006_20080705_20161228_01_T1
Narsap	LE07_L1TP_006015_20020518_20170130_01_T1	Narsap	LT05_L1TP_005015_19870915_20170211_01_T1
Nordenskiold	LE07_L1TP_022006_20010718_20170204_01_T1	Nordenskiold	LT05_L1TP_022006_19850815_20170219_01_T1
Nordfjord	LE07_L1TP_231012_20030427_20170125_01_T2	Nordfjord	LE07_L1TP_231012_20120606_20161202_01_T1
Nordfjord	LT05_L1TP_229012_19960722_20180227_01_T1	Nordre-Parallelgletsjer	LE07_L1TP_230012_20040625_20170120_01_T1
Nordre-Parallelgletsjer	LE07_L1TP_229012_20120624_20161130_01_T1	Nordre-Parallelgletsjer	LT05_L1TP_229012_19970522_20180227_01_T2
Nunatakassaap	LE07_L1TP_021007_20020831_20170128_01_T1	Nunatakassaap	LE07_L1TP_020007_20110427_20161209_01_T1
Nunatakavsaup	LC08_L1TP_015008_20150630_20170407_01_T1	Nunatakavsaup	LE07_L1TP_016008_20070522_20170103_01_T1

Continued on next page

Table S3 – *Continued from previous page*

Domain	Scene ID	Domain	Scene ID
Perlerfiup	LC08_L1TP_011010_20170709_20170717_01_T1	Perlerfiup	LT05_L1TP_011010_19890407_20170204_01_T1
Polaric	LE07_L1TP_230012_20120412_20161202_01_T2	Polaric	LT05_L1TP_229012_19960722_20180227_01_T1
Qeqertarsuup	LE07_L1TP_017008_20090806_20161218_01_T1	Rink-Gletsjer	LE07_L1TP_025006_20000415_20170212_01_T1
Rink-Isbrae	LC08_L1TP_011010_20140412_20170423_01_T1	Rink-Isbrae	LE07_L1TP_012010_20050808_20170114_01_T1
Rink-Isbrae	LT05_L1TP_013009_19860616_20170217_01_T1	Rink-Isbrae	LT05_L1TP_012010_19900519_20170130_01_T1
Rosenborg	LT05_L1TP_229012_19970420_20180227_01_T2	Saqqarliup	LE07_L1TP_009011_20060721_20170109_01_T1
Sermeq-Avannarleq-69	LC08_L1TP_008012_20181011_20181030_01_T1	Sermeq-Avannarleq-69	LE07_L1TP_008011_20090823_20161218_01_T1
Sermeq-Avannarleq-70	LC08_L1TP_011010_20140428_20170423_01_T1	Sermeq-Avannarleq-70	LE07_L1TP_009011_20080811_20161225_01_T1
Sermeq-Avannarleq-70	LT05_L1TP_010011_19940516_20170115_01_T1	Sermeq-Avannarleq-73	LE07_L1TP_016008_20010505_20170205_01_T1
Sermeq-Avannarleq-73	LT05_L1TP_019007_19910507_20180221_01_T2	Sermeq-Kujalleq-70	LE07_L1TP_010011_20040908_20170119_01_T1
Sermeq-Kujalleq-70	LE07_L1TP_011010_20130706_20161123_01_T1	Sermeq-Kujalleq-73	LC08_L1TP_018008_20180510_20180517_01_T1
Sermeq-Kujalleq-73	LT05_L1TP_017008_19870412_20170213_01_T1	Sermeq-Silarleq	LE07_L1TP_012010_20090429_20161220_01_T1
Sermilik	LE07_L1TP_011010_20040510_20170120_01_T1	Sermilik	LE07_L1TP_012010_20130323_20161124_01_T1
Sorgenfri	LE07_L1TP_229012_20000319_20170212_01_T2	Sorgenfri	LE07_L1TP_229012_20120726_20161130_01_T1
Steenstrup	LC08_L1TP_020007_20160416_20170326_01_T1	Steenstrup	LE07_L1TP_021007_20010828_20170203_01_T1
Steenstrup	LT05_L1TP_019007_19910523_20180221_01_T1	Styrtegletsjer	LE07_L1TP_229012_20000420_20170212_01_T2
Styrtegletsjer	LE07_L1TP_229012_20100416_20161214_01_T1	Styrtegletsjer	LT05_L1TP_230012_19910529_20180227_01_T1
Sverdrup	LC08_L1TP_024006_20170821_20170911_01_T1	Sverdrup	LE07_L1TP_022006_20100508_20161214_01_T1
Søndre-Parallelgletsjer	LE07_L1TP_231012_20010405_20170205_01_T2	Søndre-Parallelgletsjer	LE07_L1TP_231012_20120708_20161130_01_T1
Umiammakku	LC08_L1TP_015009_20170331_20170414_01_T1	Umiammakku	LE07_L1TP_013009_20050409_20170115_01_T1
Umiammakku	LE07_L1TP_014009_20110620_20161209_01_T1	Upernavik-NE	LC08_L1TP_015008_20130928_20170502_01_T1
Upernavik-NE	LC08_L1TP_082235_20160708_20170323_01_T1	Upernavik-NE	LC08_L1TP_082236_20190514_20190521_01_T1
Upernavik-NE	LE07_L1TP_014009_20040616_20170120_01_T1	Upernavik-NE	LT05_L1TP_017008_19950909_20180220_01_T1
Upernavik-SE	LC08_L1TP_016008_20160506_20170326_01_T1	Upernavik-SE	LE07_L1TP_014009_20090427_20161222_01_T1