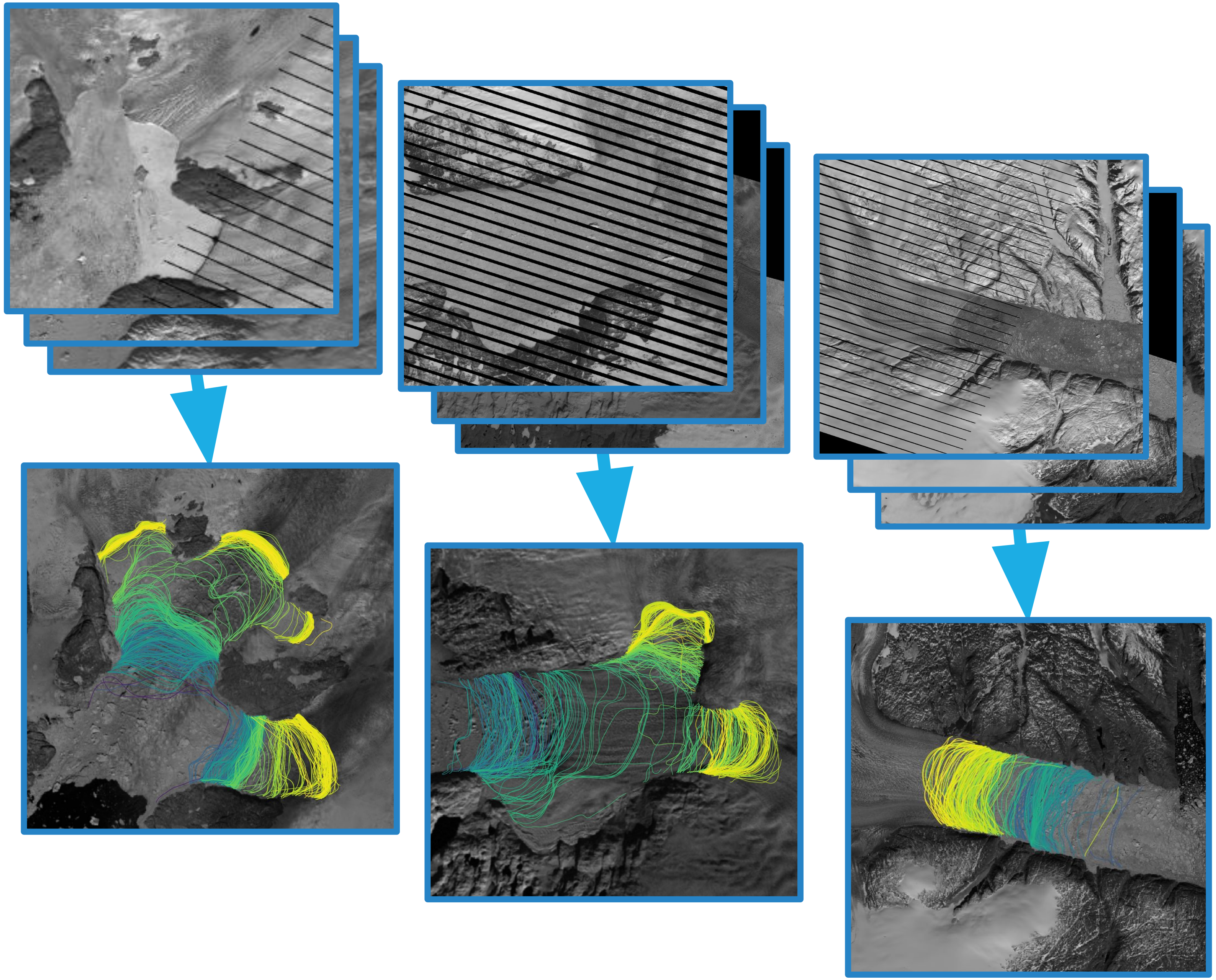


Calving Front Machine (CALFIN)

Automated Calving Front Extraction & Deep Learning Methodology

for East/West Greenland, 1972-2019

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

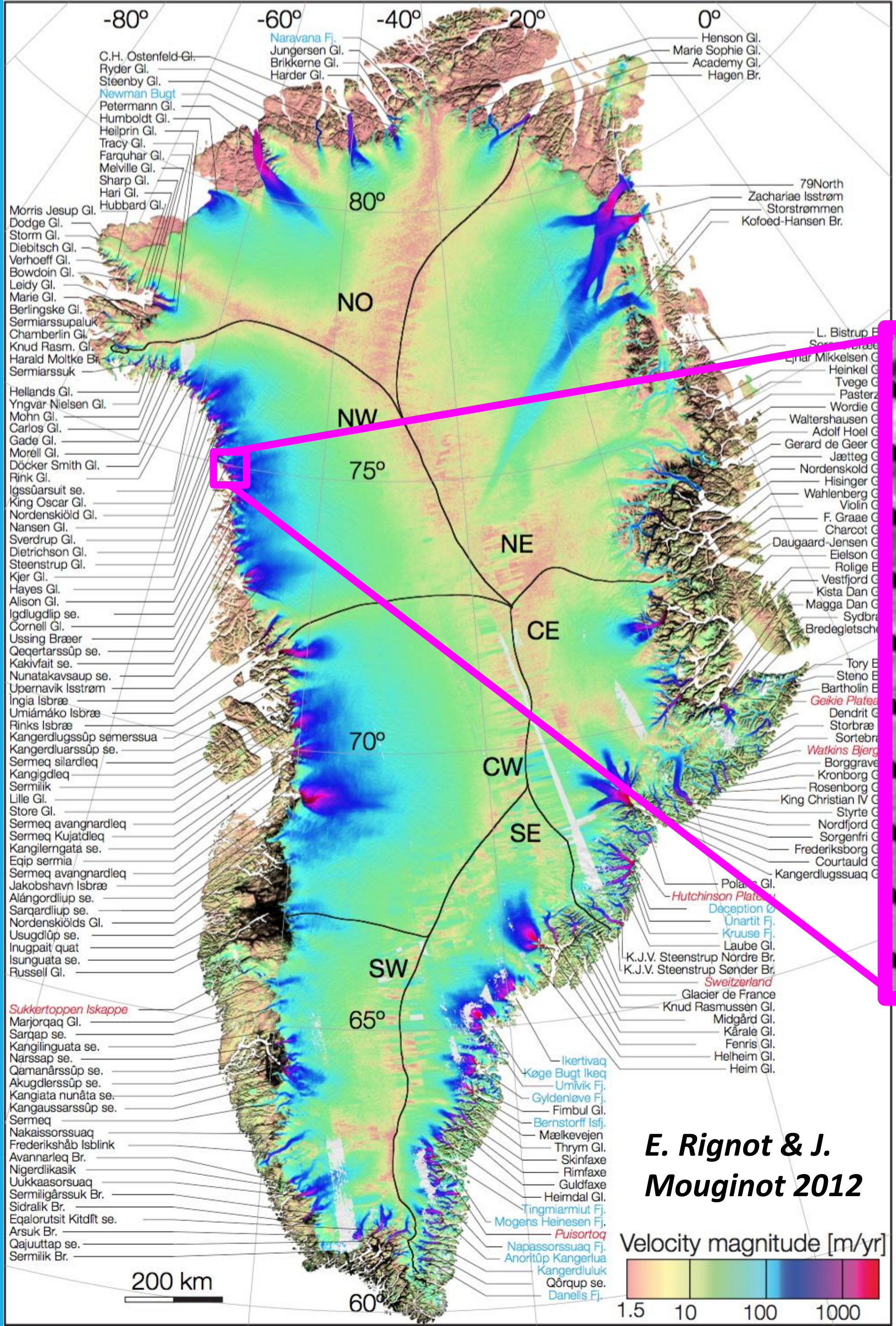
[1] University Of California at Irvine (UCI), Irvine, CA

2 California Institute of Technology - Jet Propulsion Laboratory (JPL), Pasadena, CA

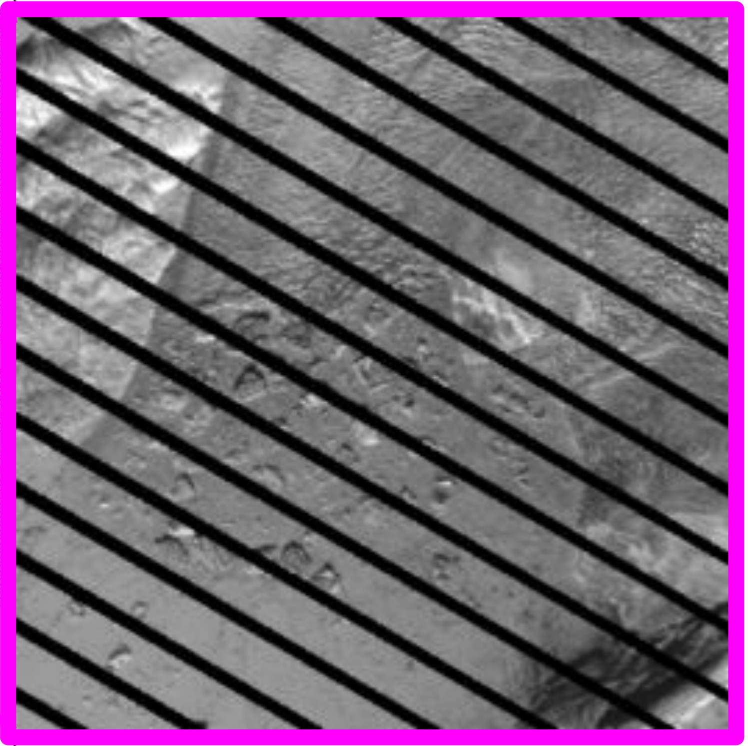
Jet Propulsion Laboratory
California Institute of Technology

Motivation

- Determining where glaciers end is useful
- Manual labeling is time intensive, automatic labeling is non-trivial
- We use Deep Neural Networks (AI/Machine learning)
- Auto-label 17000+ subseasonal fronts over 66 basins



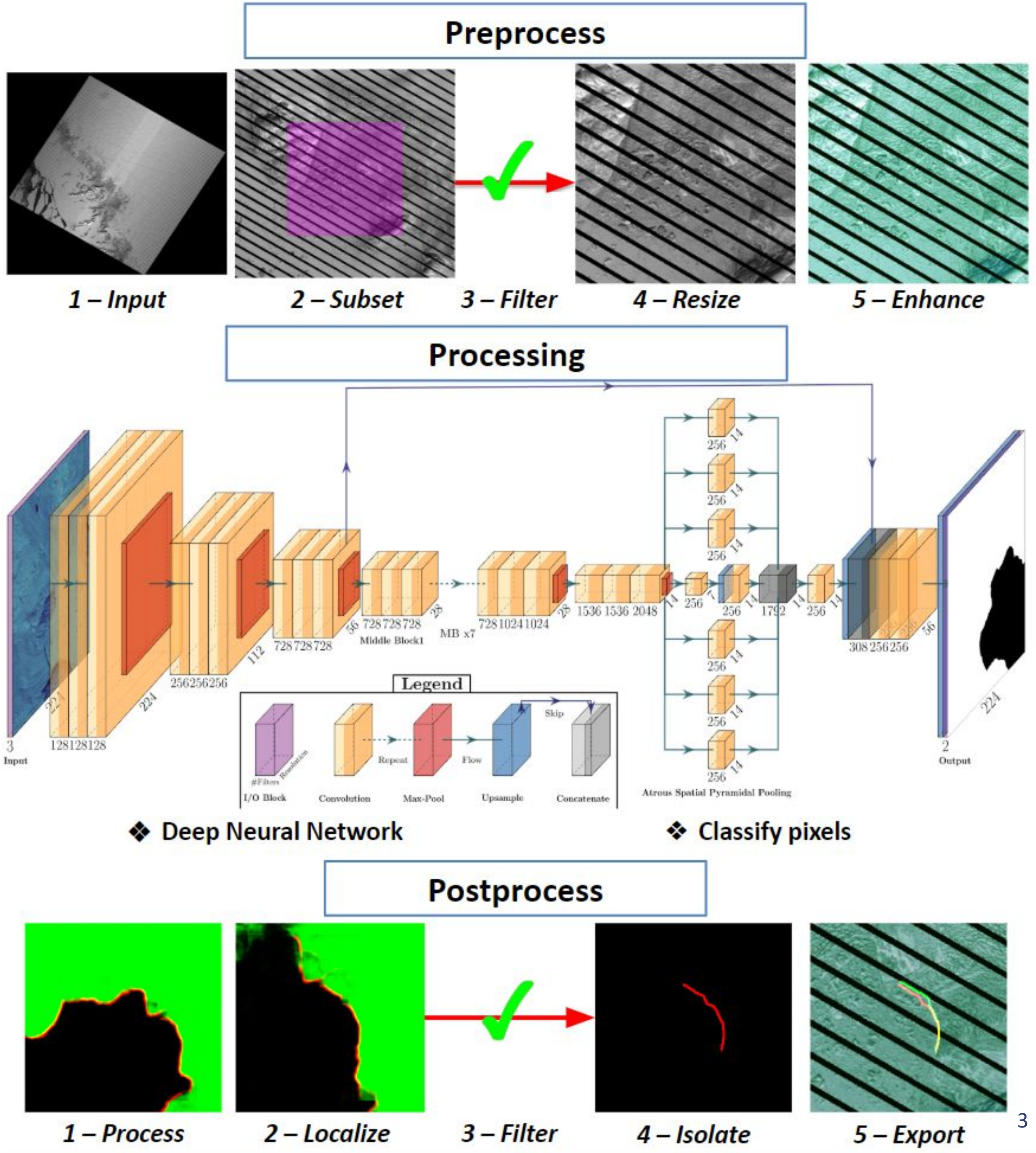
E. Rignot & J. Mouginot 2012



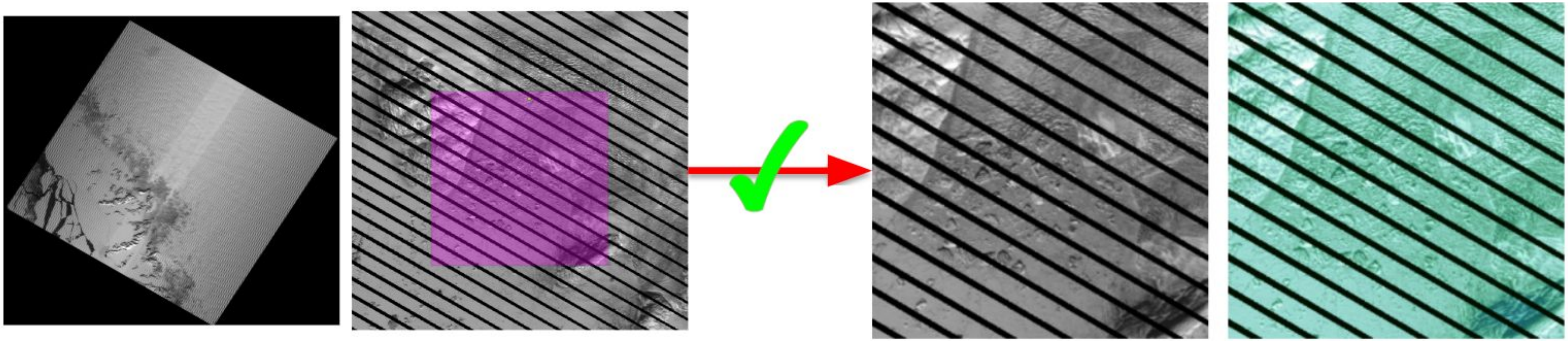
Hayes Glacier, 2006 April 06, *Landsat 7.*

Method

- Automated pipeline
- Pre-process Landsat satellite imagery
- Process and classify pixels with Neural Network
- Post-process to extract vectorized calving front



Method - Pre-processing



1 – Input
raw Landsat
GeoTIFF image
with <20% clouds

2 – Subset
using QGIS, GDAL
domain Shapefile
to subset PNG

3 – Filter
clouded/
NODATA
images

4 – Resize
subset to
256x256

5 – Enhance
by giving raw, HDR,
and auto-contrast
images to next step

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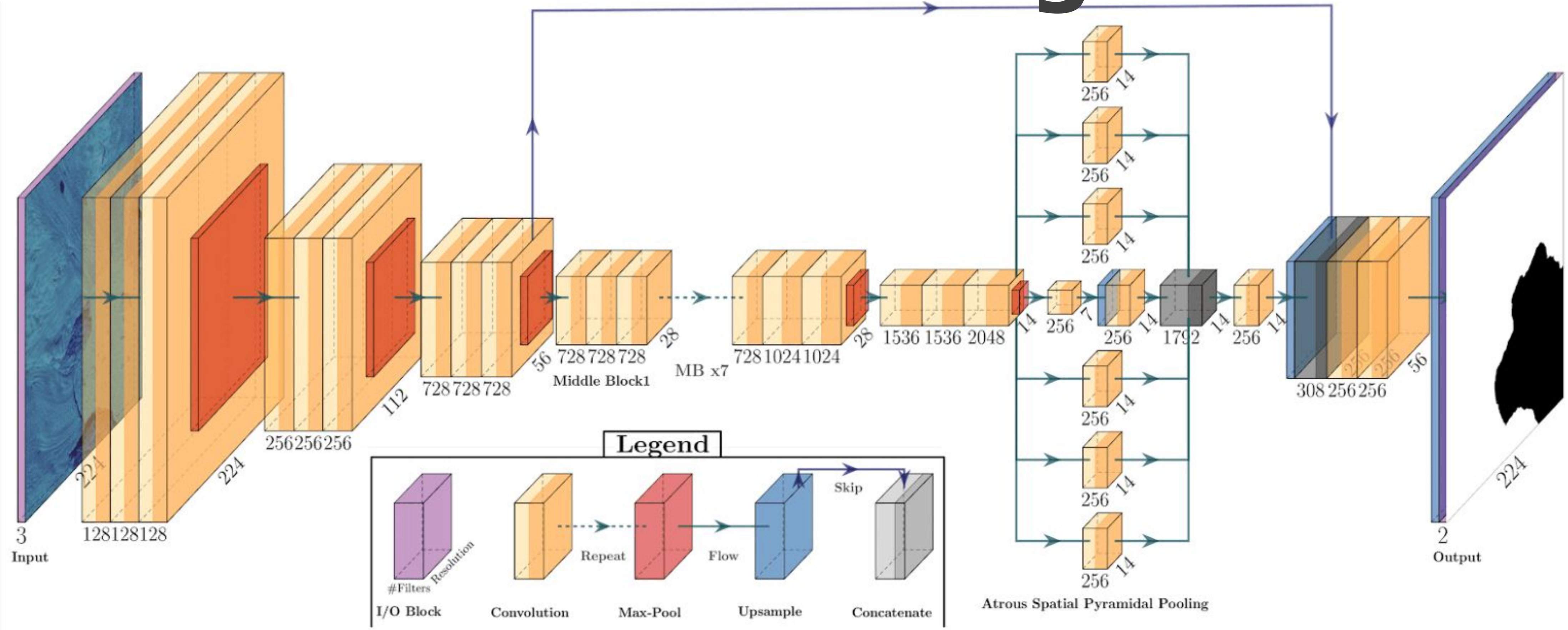
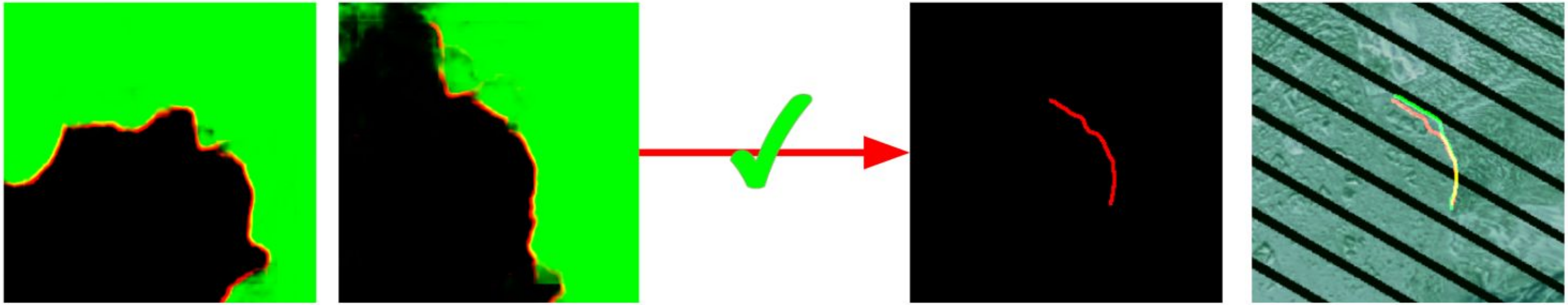
Method – Processing



- CALFIN-NN = convolutional neural network, UNet-type, DeepLabV3+ Xception derivation
  - 3 channel RGB input, 2-channel coastline/land-ice mask. ~29m parameters.
- Use 1500 manually delineated fronts for training. 65 epochs, 1wk train, 16ms inference

Method - Post-processing



1 – Get processed image

2 – Isolate and re-process each front

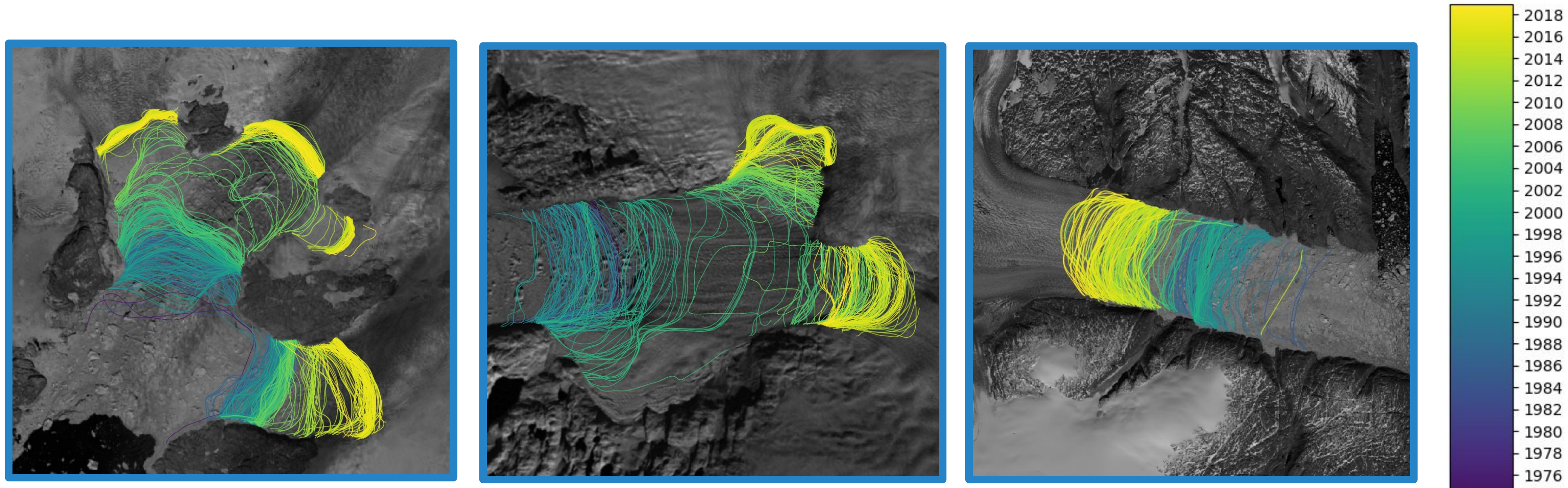
3 – Filter unconfident predictions

4 – Fit line and mask static coastline

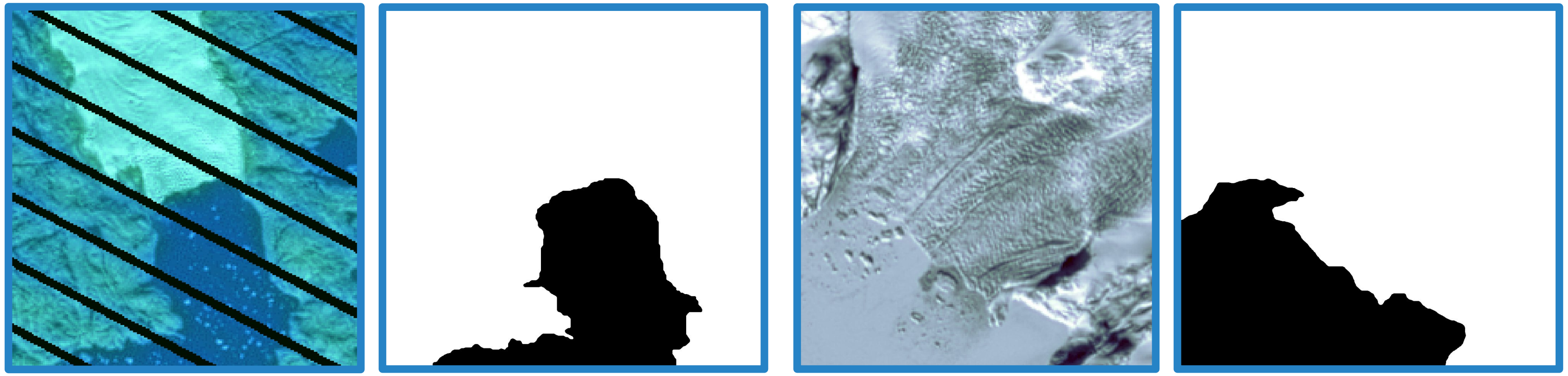
5 – Export and validate Shapefile

Results

- Data Release
  - Shapefile Polylines
    - 19909 total fronts,
      - 17912 auto-picked
      - 1997 manual
  - Includes Training data, GeoTIFF subsets, Neural Network weights
  - Release on DataDryad & NSIDC pending approval



Upernavik | Jakobshavn | Helheim

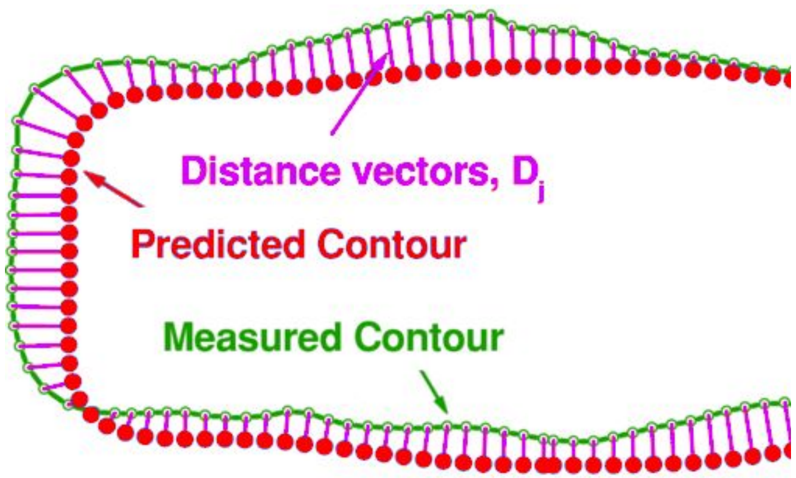


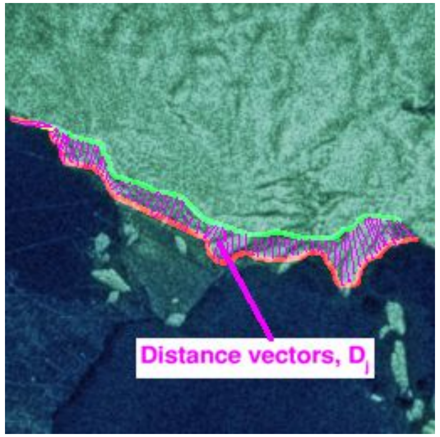
Training & validation data for 66 basins, plus 51 Antarctic basins from Zhang, Mohajerani, and Baumhoer

Results

- Measuring Error
  - Mean/Median Distance between predicted and true front
    - Calculated per pixel
    - Similar to method of transects (Baumhoer)
  - Intersection over Union
    - Measures overlap between ground truth and prediction
    - IoU Coastline = edge overlap
    - IoU Ice/Ocean = mask overlap

Mean/Median Distance





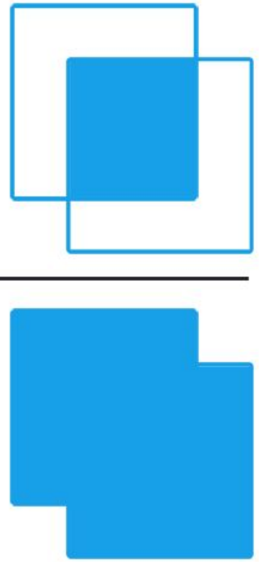
Mean Distance = mean(**D**)

Median Distance = median(**D**)

Lower = Good

Intersection over Union

$$\text{IoU} = \frac{\text{Area of Overlap}}{\text{Area of Union}}$$

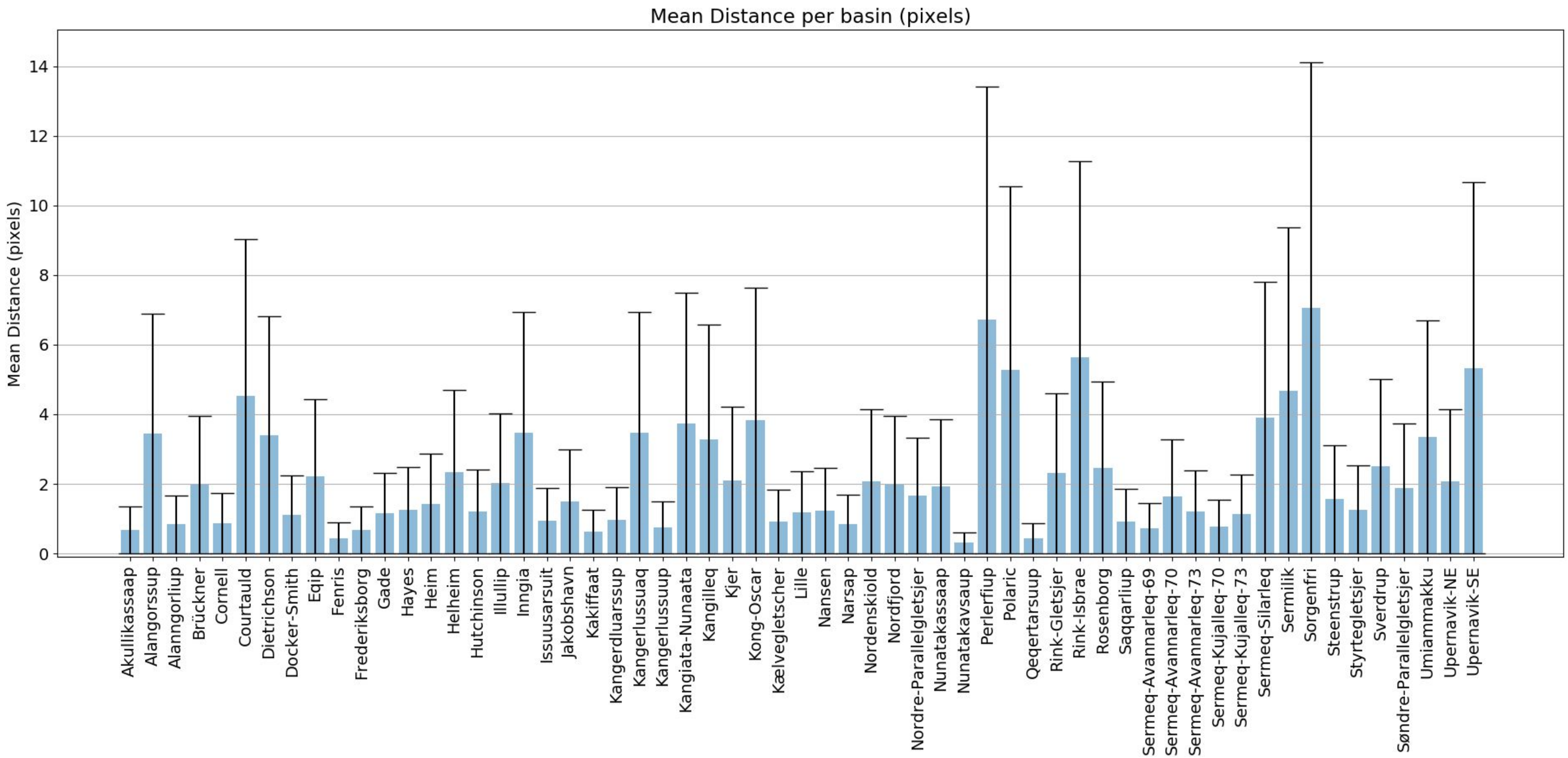


Validation Set	Model	Mean Distance	Median Distance	IoU Coastline	IoU Ice/Ocean
CALFIN	CALFIN	**2.25px, 86.76m**	1.21px, 44.59m	0.4884	**0.9793**

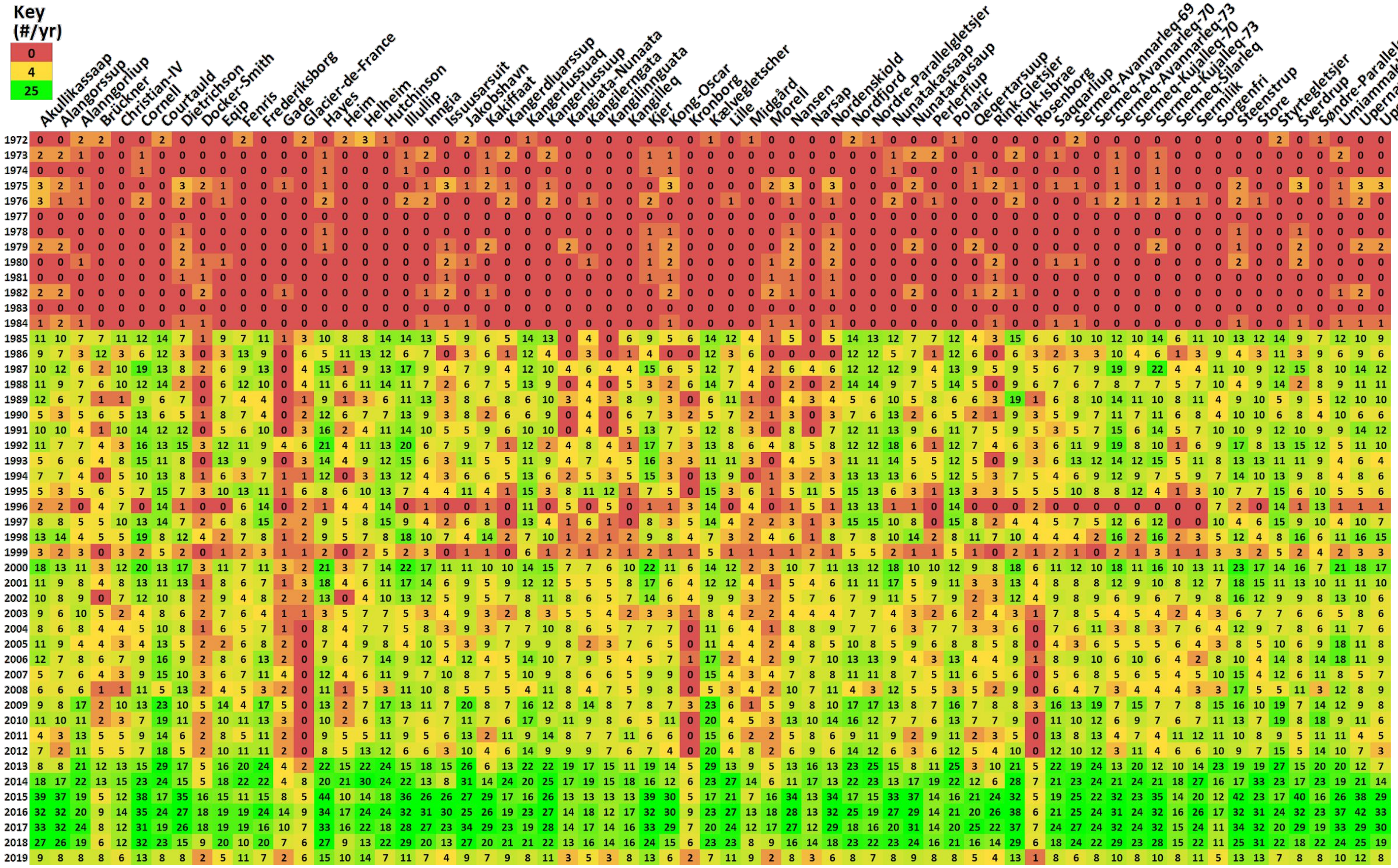
Results

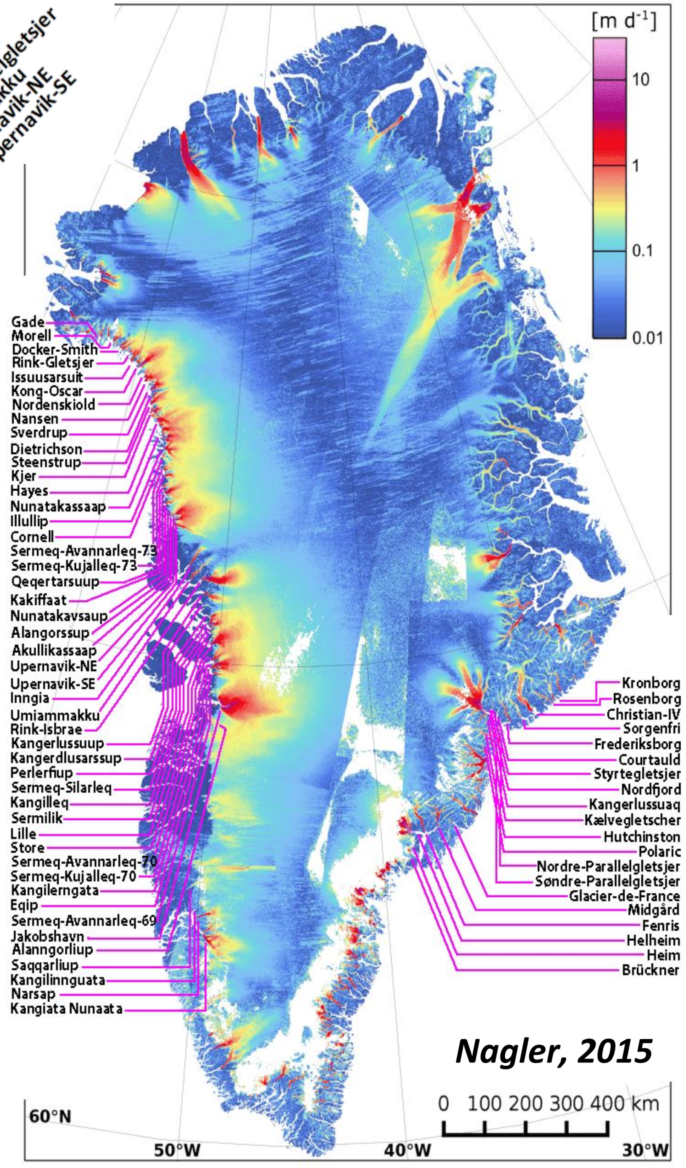
- Inter-model Comparison
  - Retrain/test UNet model by Mohajerani et al.
    - Similar median metrics
    - Outliers/L7 SCE cause issues
  - Run CALFIN on validation data from Mohajerani, Zhang, & Baumhoer
    - CALFIN is competitive and generalizes well
    - See EGU2020-4486 for Celia Baumhoer's work

Validation Set	Model	Mean Distance	Median Distance	IoU Coastline	IoU Ice/Ocean
CALFIN	CALFIN	**2.25px, 86.76m**	1.21px, 44.59m	0.4884	**0.9793**
CALFIN	Mohajerani	4.45px, 201.35m	1.25px, 50.52m	**0.4935**	0.9699
Mohajerani	CALFIN	2.56px, 97.72m	2.55px, 97.44m	0.3332	N/A
Mohajerani	Mohajerani	**1.97px, 96.31m**	N/A	N/A	N/A
Zhang	CALFIN	**3.56px,** 284.22m	1.69px, 114.50m	0.3739	0.9778
Zhang	Zhang	17.3px, **104m**	N/A	N/A	N/A
Baumhoer	CALFIN	3.36px, 543.47m	0.95px, 127.87m	0.5959	**0.9873**
Baumhoer	Baumhoer	**2.69px, 108m**	N/A	N/A	0.905



Results - Mean Distance Intervals by Basin





Results - Spatial/Temporal Coverage

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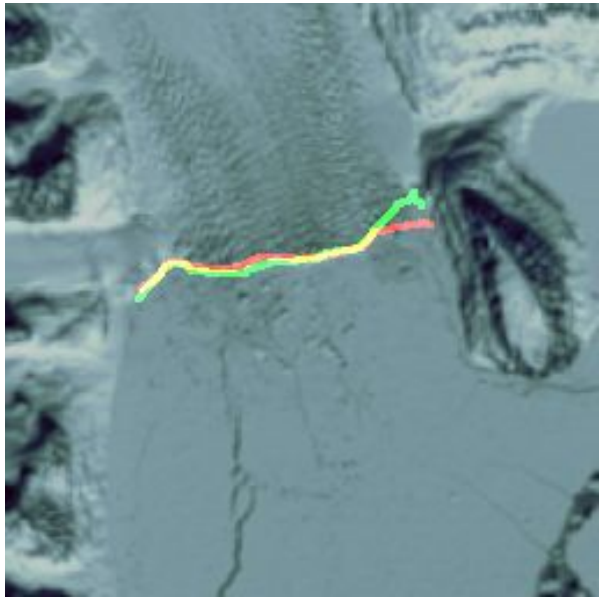
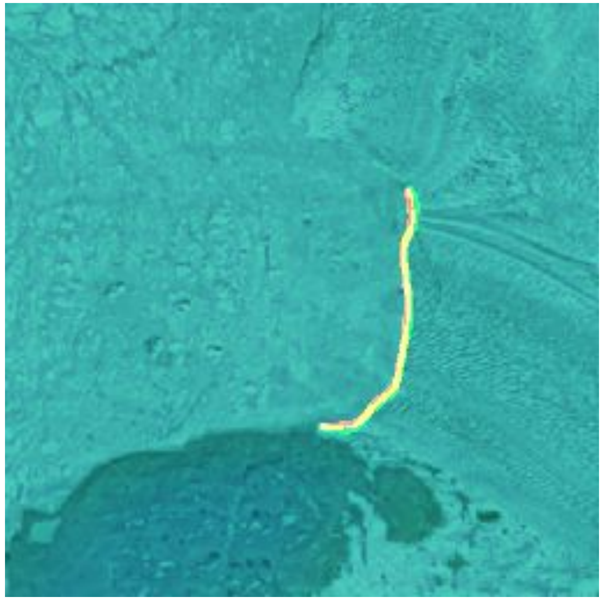
Error Analysis

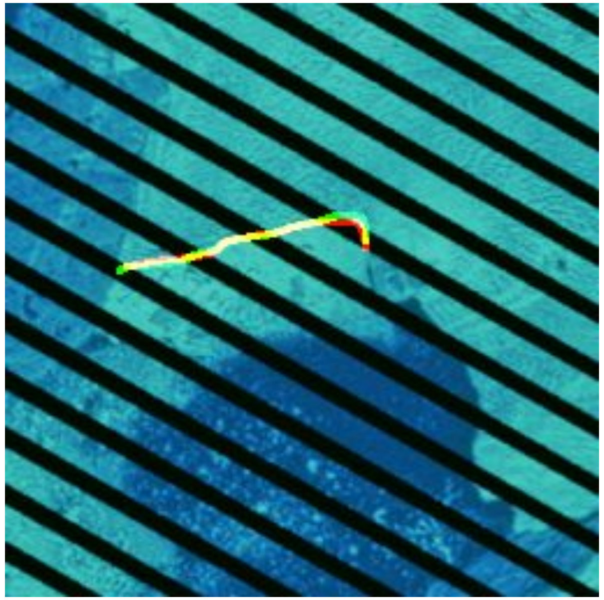
- Validation set
  - 162 unseen images
  - Most adverse conditions handled well
  - Ice tongues need work
  - Mean Error:
    - 2.25 ± 0.02 pixels
    - 86.76 ± 0.73 meters



Rosenborg 1997-04-20



Jakobshavn-E 2017-06-02



Hayes-N 2008-08-10

Kong-Oscar 1998-03-26

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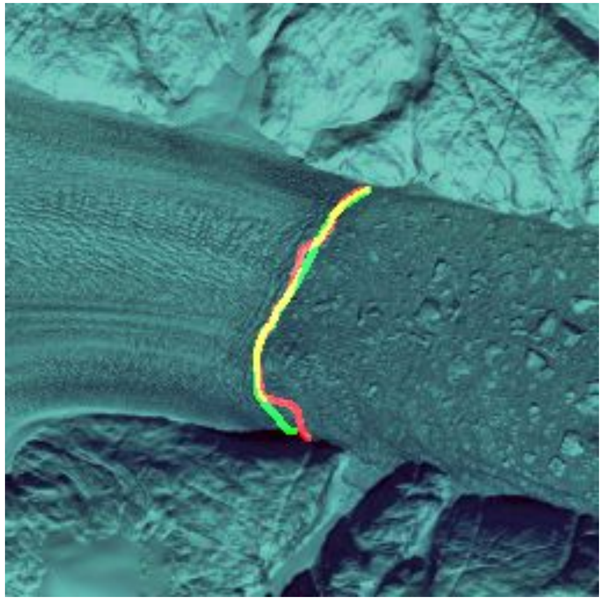
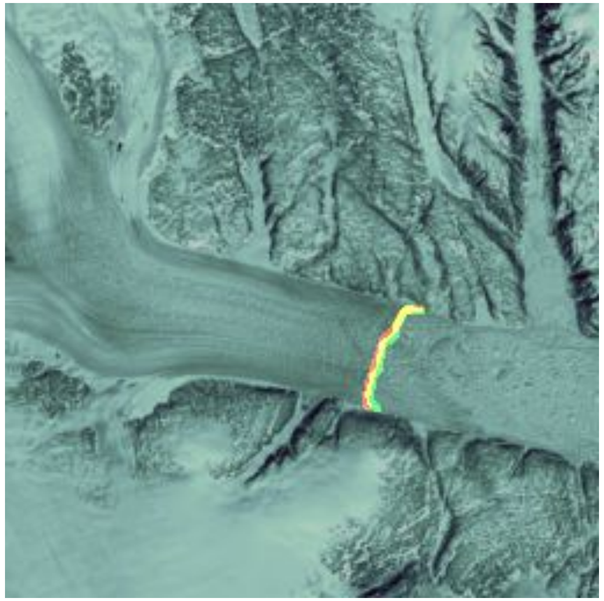
Error Analysis

- Helheim
  - Handles Multiscale/L7 SCE
  - Error near fjord walls
  - Provides strong proof of generalization
  - Mean Error:
    - 2.34 ± 0.12 pixels
    - 124.05 ± 6.40 meters

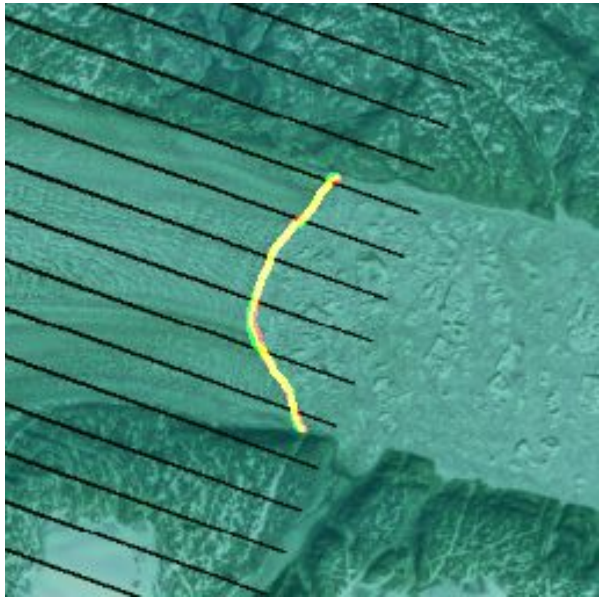


Helheim 2013-04-12

Helheim 2000-05-27



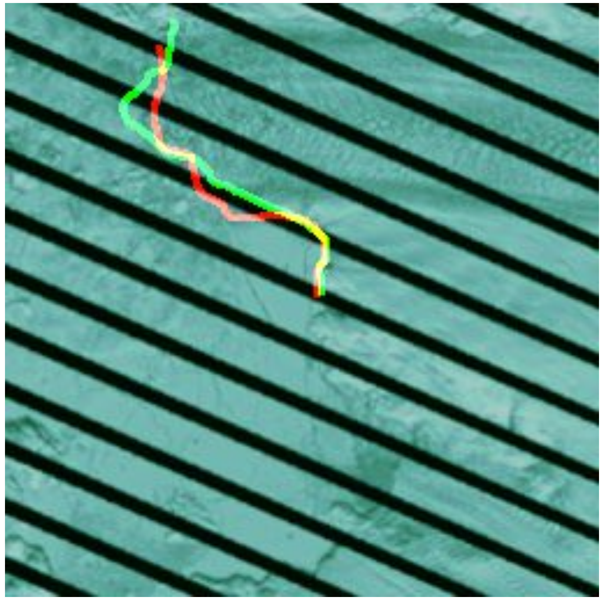
Helheim 1993-06-08

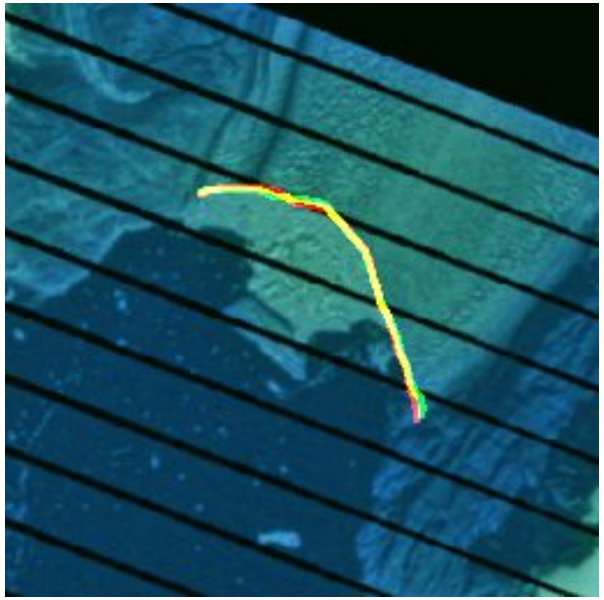


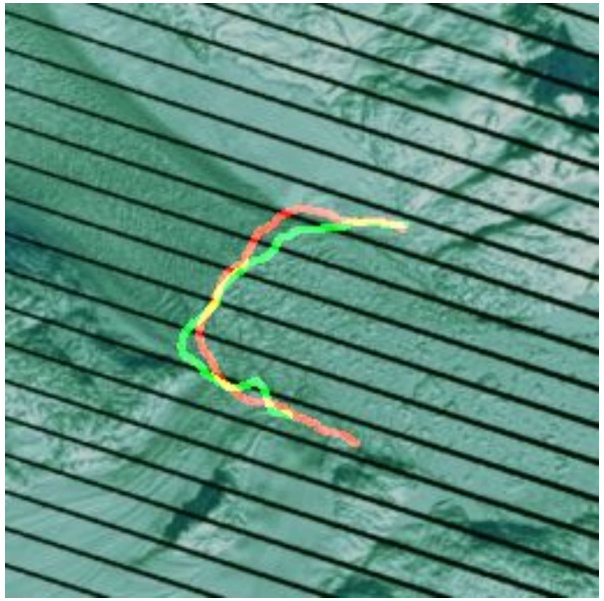
Helheim 2003-08-08

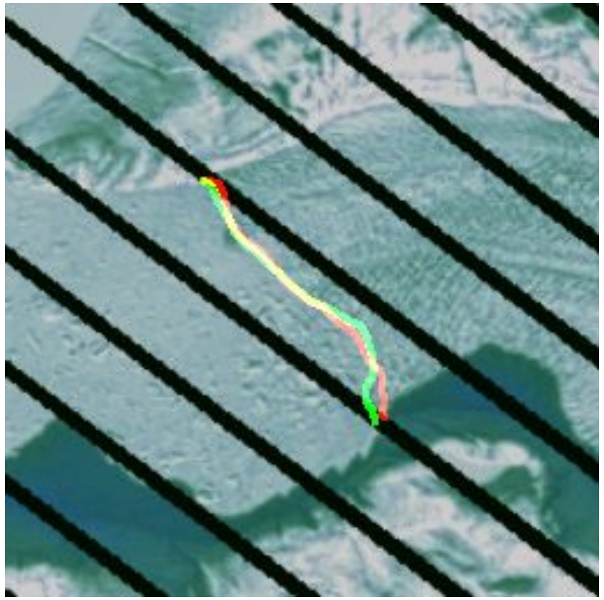
Error Analysis

- L7 Scanline Errors
  - Higher than average error as expected, but still good
  - No L7 SCE Mean Error:
    - 2.27 ± 0.07 px, 81.65 ± 2.65m
  - Only L7 SCE Mean Error:
    - 2.22 ± 0.07 px, 91.93 ± 3.04 m


Upernavik-SE_2009-04-27

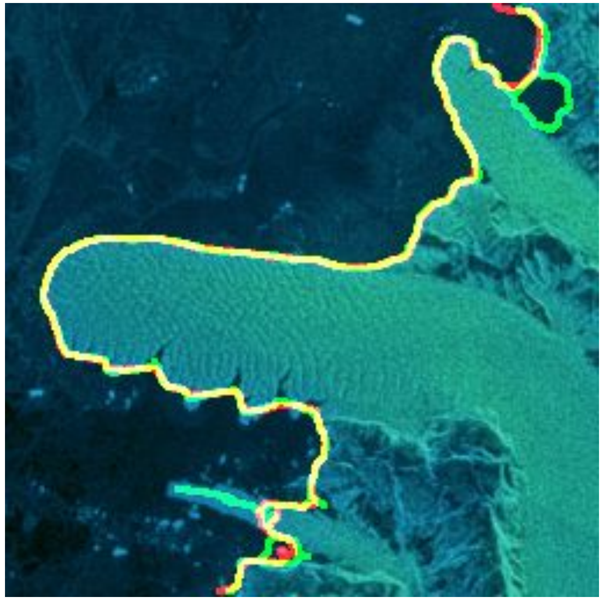

Rink-Isbrae 2005-08-08


Kangerlussuaq 2012-04-19

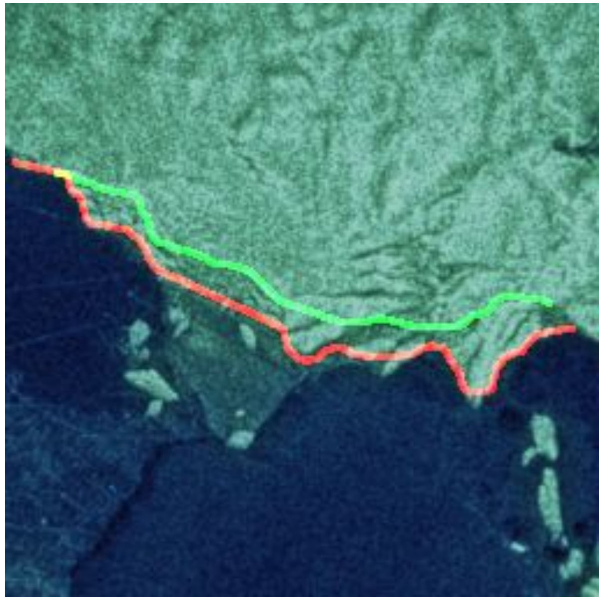

Dietrichson 2008-04-23

Error Analysis

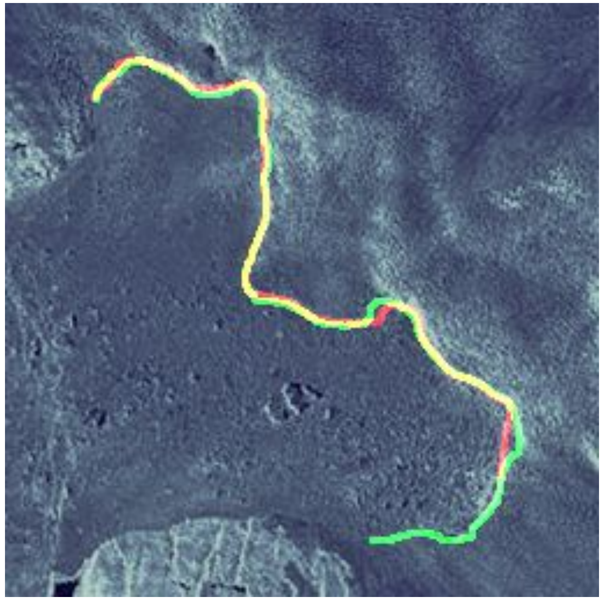
- Non-Landsat data
  - More training needed
  - Zhang TerraSAR-X Error:
    - 3.56px, 284.22m
  - Baumhoer Sentinel-1 Error:
    - 3.36px, 543.47m
  - MODIS too low res (250m)



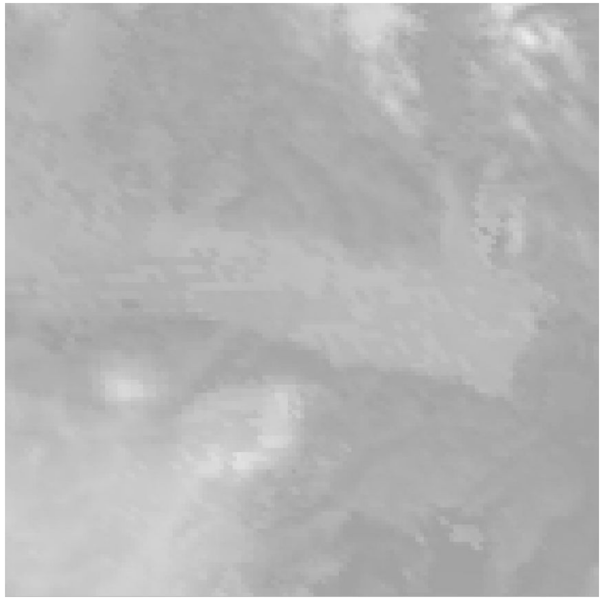
Aviator TSX 2018-06-29



Gillet S1B 2018-06-26



Jakobshavn TSX 2014-07-03



Helheim MODIS 2015-09-27

Conclusion & Future Work

- Publication & Data Release still in progress!
- Accuracy target for release: <100m for all domains achieved
  - Increased Accuracy, Spatial Resolution, Spatial Coverage
  - Multi-sensor handling (Sentinel/SAR)
- Collaboration with IcePicks
  - See Sophie Goliber in this session at EGU2020-11237
  - Other Feature Detection (iceberg, grounding line, sediment plume, etc.)
  - Unified Calving Front/Feature Database

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Thank you!

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov - uci.edu

Daniel Cheng - dlcheng@uci.edu
Wayne Hayes - whayes@uci.edu
Eric Larour - Eric.Larour@jpl.nasa.gov
Yara Mohajerani - ymohajer@uci.edu
Michael Wood - mhwood@uci.edu
Isabella Velicogna - isabella@uci.edu
Eric Rignot - erignot@uci.edu

Thanks @ ISSM Team, Friends, and Family

References & Related Work

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- **Celia A. Baumhoer, Andreas J. Dietz, and Claudia Kuenzer.** Automated Extraction of Antarctic Glacier and Ice Shelf Fronts from Sentinel-51 Imagery Using Deep Learning, Remote Sensing, 11, 2529.
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- **Jukes Liu, Ellyn Enderlin, Andre Khalil.** "Greenland Marine Glacier Terminus Mapping in Satellite Imagery Using the Automated 2D Wavelet Transform Modulus Maxima (WTMM) Segmentation Method." AGU, AGU, 11 Dec. 2019
- **Soroush Rezvanbehbahani, Leigh Stearns, Ramtin Keramati, Siddharth Shankar.** Automating Iceberg Detection in Greenland Using Deep Learning on High to Moderate-Resolution Optical Imagery. AGU, AGU, 11 Dec. 2019

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