Analog data of Jakobshavn Isbræ: improving SfM photogrammetric processing

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Funding Sources: NSF 1561064 NSF 1950681

I. Introduction

- Four flight campaigns from Jakobshavn Isbræ over 1985 and 1986 (Figure 1).
- Lead by Terry Hughes (University of Maine) and Henry Brecher (Ohio State).
- Flown by Marc Hurd Inc. and Keystone Aerials using a Wild RC-10 camera.
- The original film negatives were digitized by Roman Motyka (UAS) in 2006.
- Initial structure-from-motion photogrammetric processing of 1985 aerials produced poor results due to inadequate ground control distribution of stable terrain (exposed bedrock only covers ~1/3 of the air photo extent).
- Surface elevations were derived from the air photos in the 1980s from Doppler satellite ground control (Fastook et al., 1995).
- Using a derivative of the original 1980s generated elevations (e.g., isochrons), ground control can be extended over the ice sheet allowing for improved SfM results and elevation change alanysis.

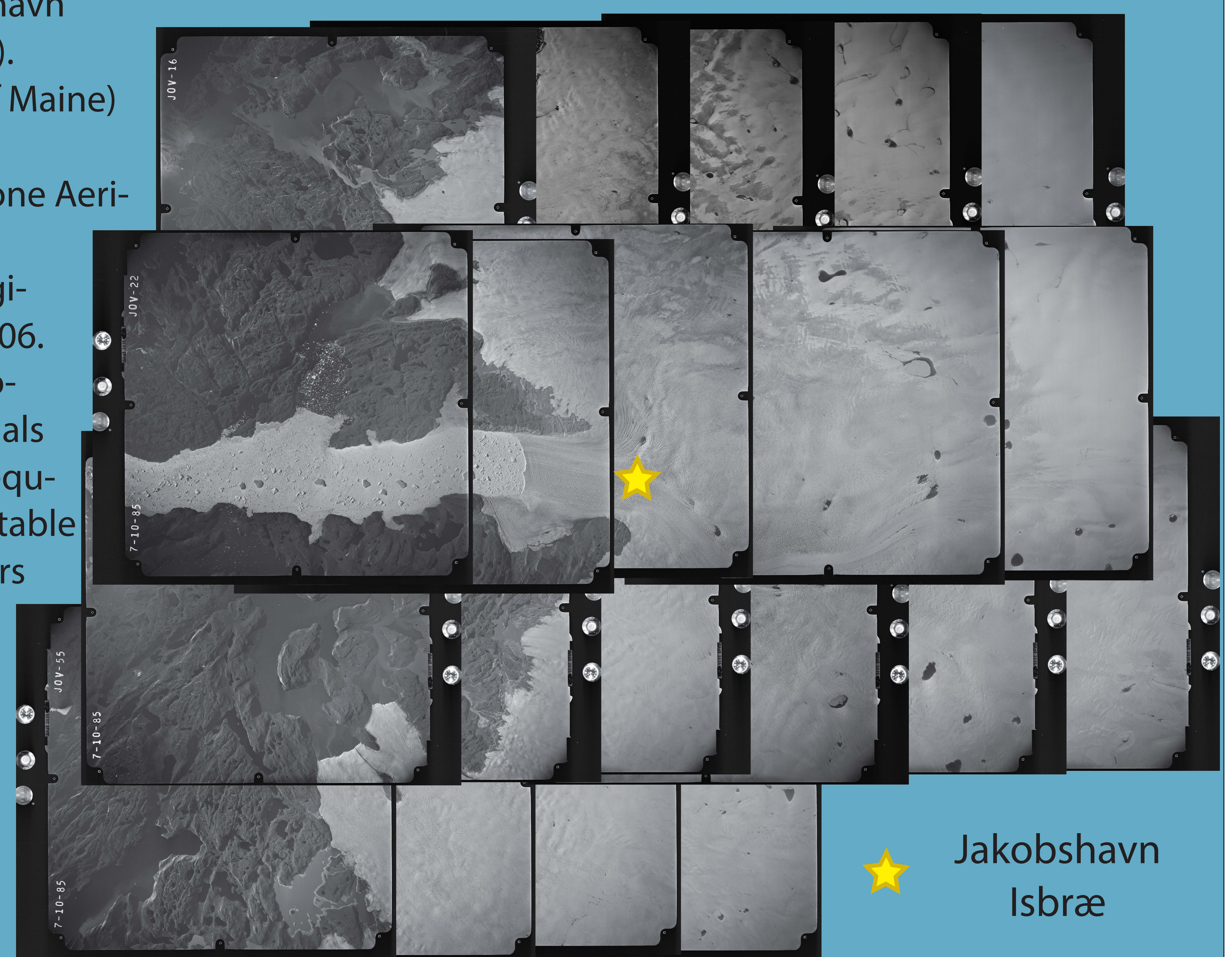

Figure 1: Uncorrected mosaic of a sample of the July 10, 1985 aerials collected over Jakobshavn Isbræ. The majority of the data extent excludes stable terrain which lead to failed SfM photogrammetric processing where ground control was limited to the rock outcrop features. These photos were acquired at a high mean altitude of 13,650 m making the scale 1:130,000 and the image spatial resolution 2 m.

II. Methodology

14 ortho/contour film negative sheets scanned at 1,000 dpi

↓

Orthos georeferenced and contours digitized in QGIS

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Contours = mean sea level heights via GEM10-B geoid

↓

1980s Ground Control = WGS72 Ellipsoid

↓

Present-Day Elevations = WGS84 Ellipsoid; Molodensky transformation

↓

1985 DEM (100 m) = Ordinary Kriging interpolation of WGS84 contours

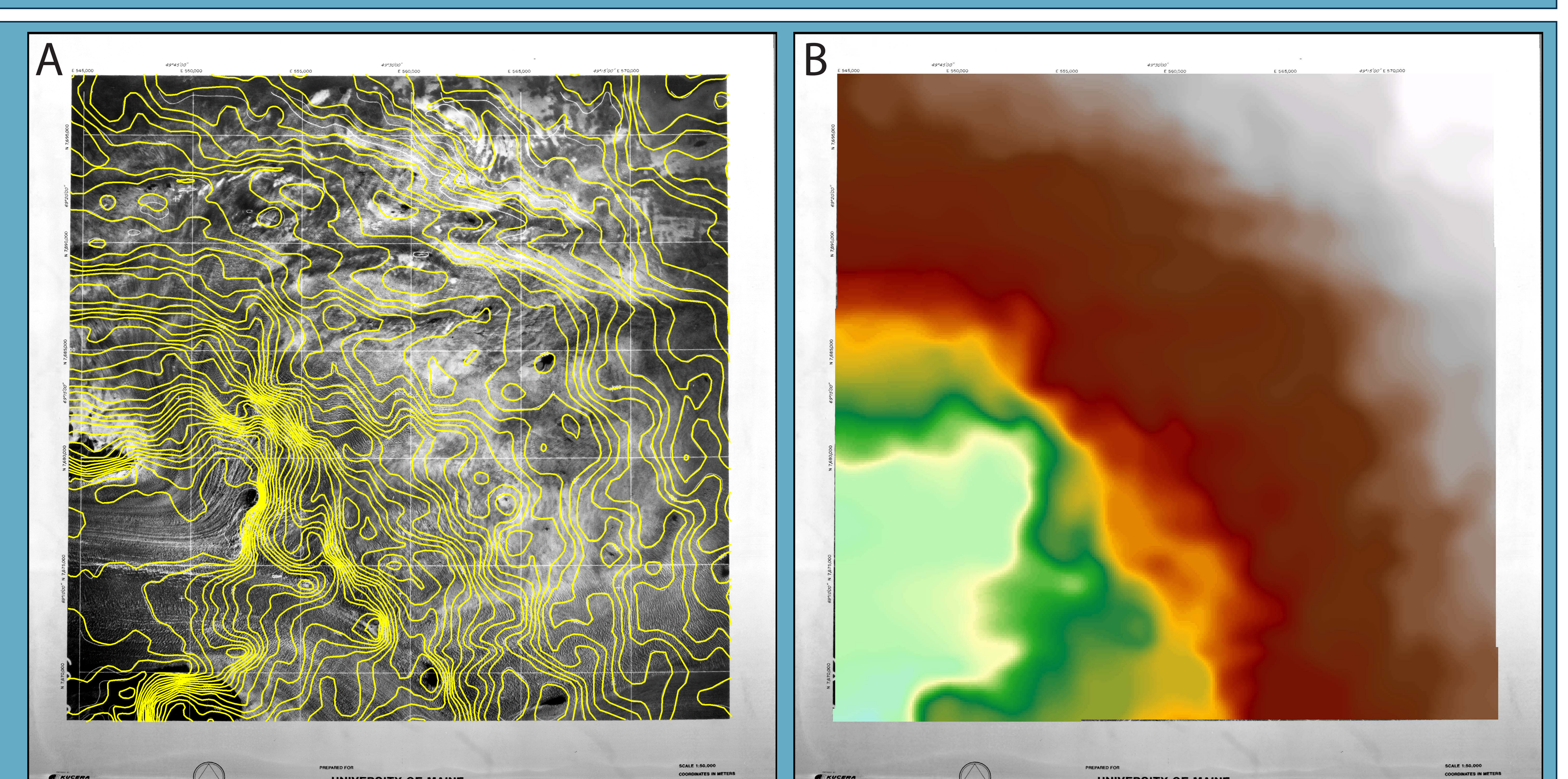

Figure 2: A) Example of othro-photo contour film negatives (Sheet No. 28) with the 20 m interval contour lines digitized in yellow isochrons. B) The resulting interpolated DEM at 100 m grid spacing.

Standard Molodensky Transform (NIMA, 2000)

$$\Phi_{WGS84} = \Phi_{WGS72} + \Delta\Phi \quad (\Phi\text{: Geodetic Latitude})$$
$$\lambda_{WGS84} = \lambda_{WGS72} + \Delta\lambda \quad (\lambda\text{: Geodetic Longitude})$$
$$h_{WGS84} = h_{WGS72} + \Delta h \quad (h\text{: Ellipsoidal height})$$

$$\Delta\Phi'' = -\Delta X sin\Phi cos\lambda - \Delta Y sin\Phi sin\lambda + \Delta Z cos\Phi + \Delta a \frac{R_n e^2 sin\Phi cos\Phi}{a} + \Delta f \left[R_m + R_n\left(\frac{b}{a}\right)\right] sin\Phi cos\Phi \cdot [(R_m + h)sin1'']^{-1}$$
$$\Delta\lambda'' = [-\Delta X sin\lambda + \Delta Y cos\lambda] \cdot [(R_n + h)cos\Phi sin1'']^{-1}$$
$$\Delta h = \Delta X cos\Phi sin\lambda + \Delta Y cos\Phi sin\lambda + \Delta Z sin\Phi - \Delta a\left(\frac{a}{R_n}\right) + \Delta f\left(\frac{b}{a}\right) R_n sin^2\Phi$$

Translations: $\Delta X = 0.0$; $\Delta Y = 0.0$; $\Delta Z = 4.5$

$a = 6378135$ (WGS72 semi-major axis)

$\Delta a = 2.0\ m$ (WGS72-WGS84 semi-major axes Difference)

$b = 6356750.5$ (WGS72 semi-minor axis)

$\frac{b}{a} = 1 - f$

$f = 298.26$ (Flattening)

$\Delta f = 0.3121057\times10^{-7}$ (WGS72-WGS84 Flattening Difference)

$e^2 = 2f - f^2$ (e: First eccentricity)

$$R_n = \frac{a}{(1 - e^2 sin^2\Phi)^{1\backslash 2}} \quad \text{(Radius of curvature in prime vertical)}$$

$$R_m = \frac{a(1 - e^2)}{(1 - e^2 sin^2\Phi)^{3\backslash 2}} \quad \text{(Radius of curvature in meridian)}$$

III. Results

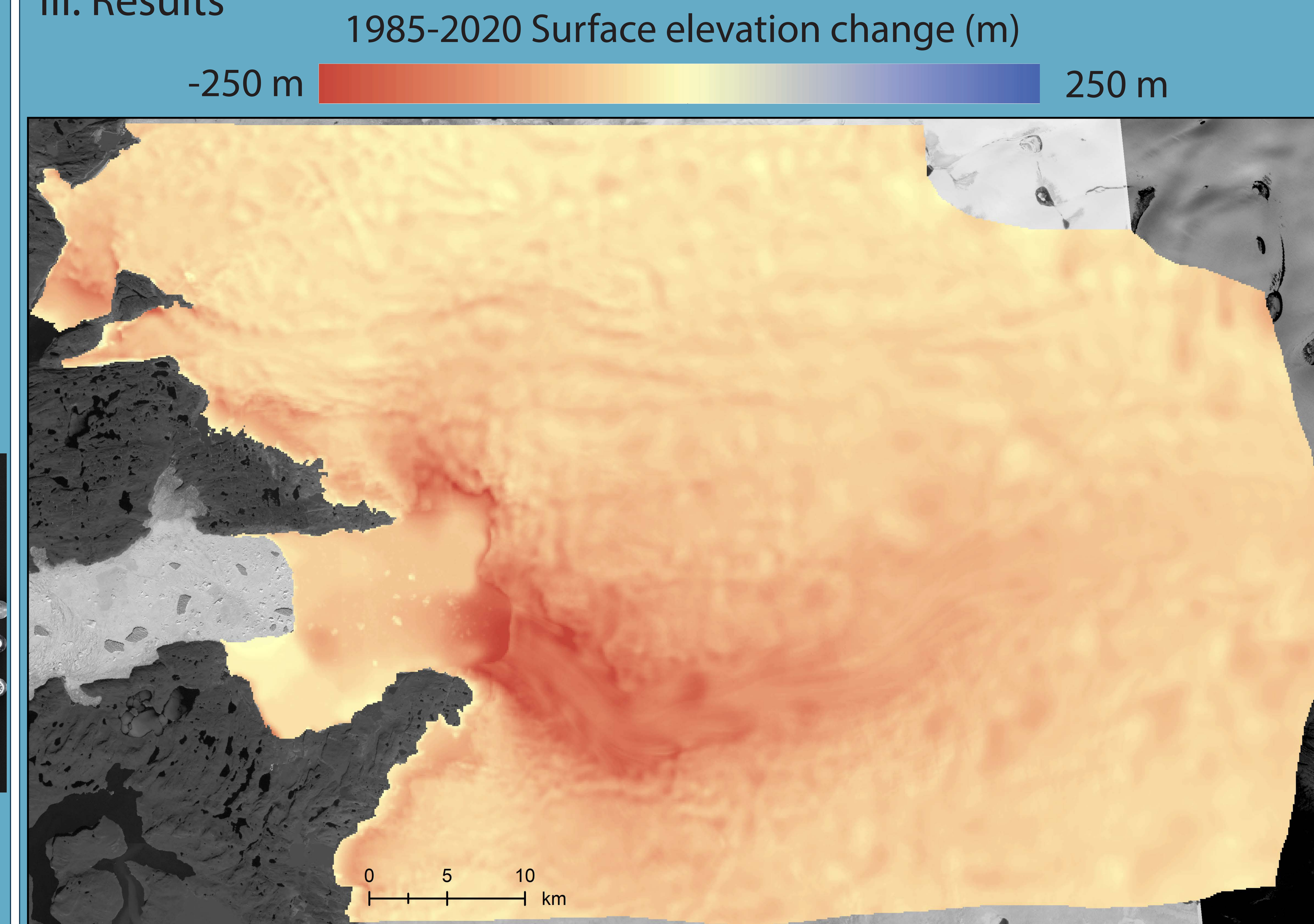

Figure 3: Elevation change results from 1985-2020. Negative values regesent surface lowering.

- The 1985 DEM was co-registered to 2020 ArcticDEM (Porter et al., 2018) 2 m strips (Noh and Howat, 2015) using the technique outlined in Nuth and Kääb (2011) over stable terrain (e.g., rock outcrop).

- Tidal corrections performed with the CATS2008 model (Padman, 2002).
- The mean elevation difference of study-site is ~75 m (Figure 3).
- This excludes ~14 km of the 1985 floating section.
- Greatest surface lowering, ~285 m, near present-day grounding line location.
- Results are similar with Motyka et al, (2010).
- ~5 m vertical accuracy (standard deviation of 2.3 m) over stable terrain.
- SfM processing will be re-run using converted ice sheet ground control XYZ values.

IV. Discussion/ Future Work

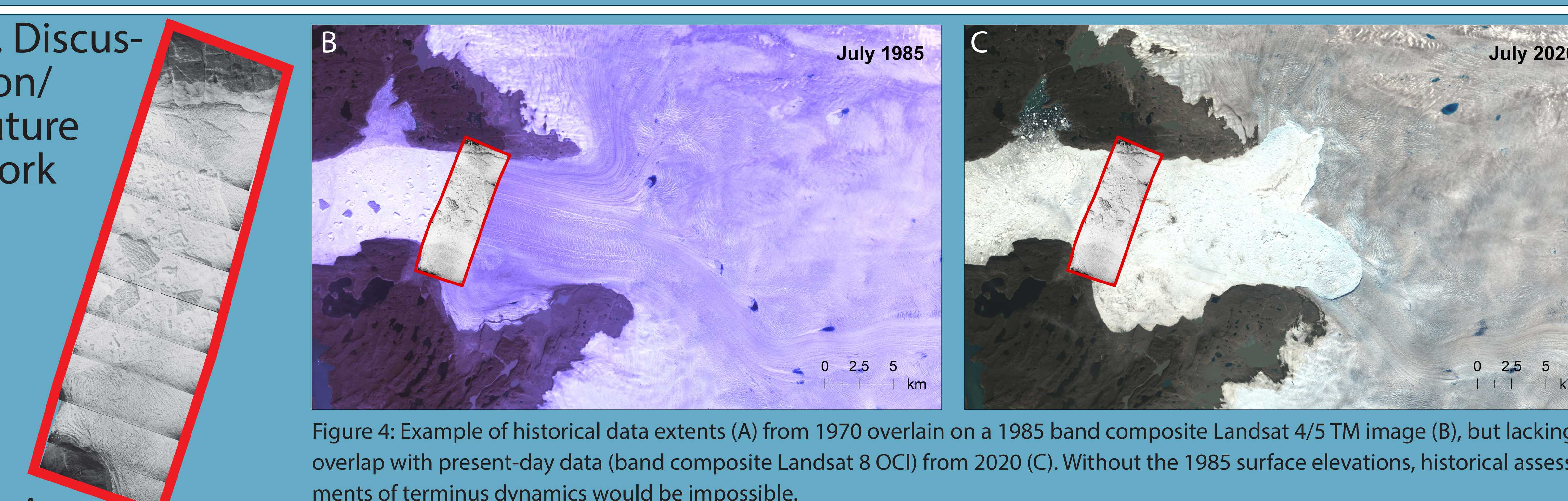

Figure 4: Example of historical data extents (A) from 1970 overlain on a 1985 band composite Landsat 4/5 TM image (B), but lacking overlap with present-day data (band composite Landsat 8 OCI) from 2020 (C). Without the 1985 surface elevations, historical assessments of terminus dynamics would be impossible.

- In 1970, the U.S. Coast Guard collected data from West Greenland that included a strip of photos over Jakobshavn Isbræ's floating portion (Figure 4A).
- The 1970 data extent does not overlap with the 2020 glacier extent (Figure 4B and 4C), but it does with 1985's.
- The mean difference of floating 1970 and 1985 elevations is ~2 m.
- The 1985/86 air photos fill a critical spatio-temporal gap between present-day and historical datasets (Figure 5).
- The 1980s aerials highlight the affect temporal resoltuion has on glacier dynamics studies.

Figure 5: U.S. Air Force oblique photos from 1942 looking up-flow Jakobshavn Isbrae. Processing elevation change from these images would be impossible w/o an enhanced temporal resolution due to significant 80-year changes. Note the 1942 terminus position is located farther down-flow than its 1970 limit by an approximate 1.5-2.5 km.