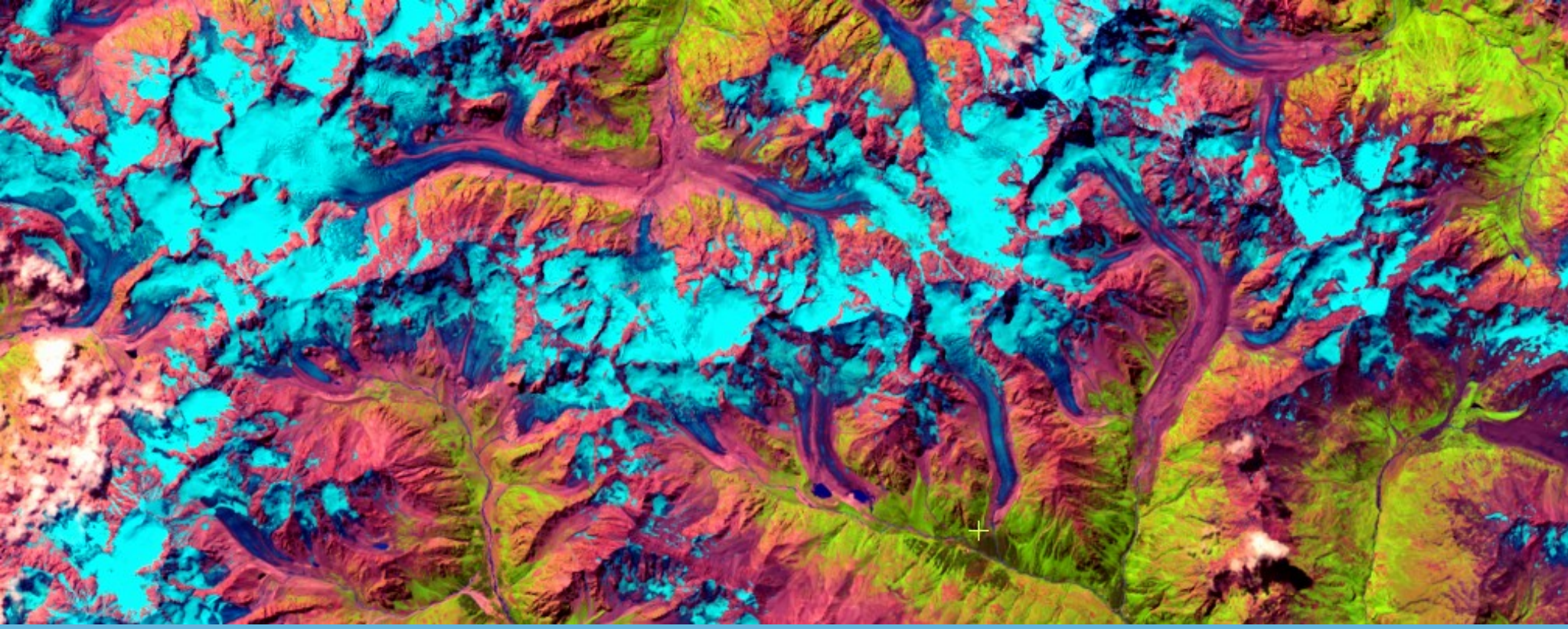
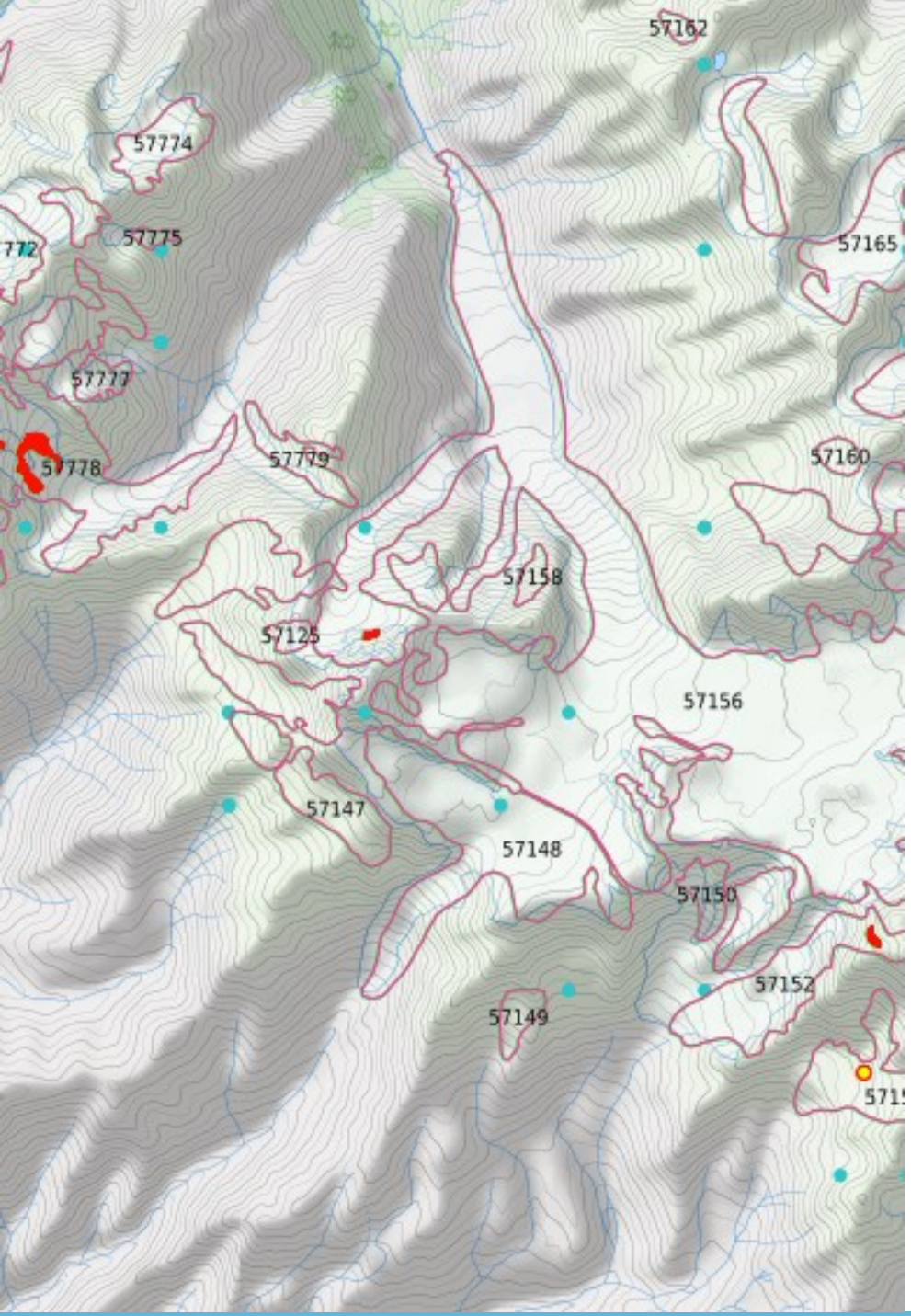


GLACIER EXTENTS OF THE GREATER CAUCASUS MOUNTAIN RANGE DERIVED FROM MANUAL INTERPRETATION AND DIGITAL CLASSIFICATION OF LANDSAT SATELLITE DATA

By : Kate Doyle Supervisors: Roger Wheate, Nikolas Prechtel, Corné van Elzakker

WHY IS IT IMPORTANT TO STUDY GLACIERS?


57162
57774
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57149

THE GREATER CAUCASUS

RUSSIA
GEORGIA
AZERBA
ARMENIA
Stavropol'
Kray
Kislovodsk
Pyatigorsk
Mozdok
Kizlyar
Kabardino-Balkaria
Nal'chik
Nartkala
Chechenia
Groznyy
Gudermes
Ingushetia
North Ossetia
Vladikavkaz
Dagestan
Makhachka
T'bilisi
Rust'avi
Gori
Khashuri
Borjomi
Akhalts'ikhe
Zugdidi
Kutaisi
Batumi
Kars
Gyumri
Vanadzor
Dilijan
Gäncä
Yerevan
Nakhichevan
(AZERBAIJAN)
Naxçıvan
Bärdä
Şaki
Lahıc
Qusar
Quba
Şamaxı
Ağdam
Xankändi
Şuşa
Füzuli
Horadiz
Lerik
Astara
Cälilabad
Masallı
Yevlax
Mingäçevir
Sevana Lich
Kür (Kura)
Aras
Terek
Kuma
Kubani
Baksan
Malka
Sunzha
Argun
Aragats
Ararat
Sevan
Ararat
Mäkü
Patnos
Malazgirt
Erciş
Karaköse
Doğubayazıt
Eleşkirt
Kağizman
Sarıkamış
Ardahan
Akçay
Tuzluca
Iğdır
Aralık
Sarur
Şahbuz
Kapan
Qubadli
Zangilan
Laçın
Goris
Sisian
Kajaran
Culfa
Ordubad
Meghri
Aläjüjeh
Seyah Cheshmeh
Muradiye
Çaldıran
Bulanık
Sarısu
Tahir
Horasan
Karakurt
Karaçan
Tutak
Hamur
Taşlıçay
Diyadin
Patnos
Bäzargän
Pürnäk
Margan
Näzik-e Olyä
Pol Dasht
Kok
Cänni
Nehram
Paraqaçay
Şärur
Vayk
Angegnadzor
Yeghegnadzor
Jermuk
Martuni
Vardenis
Sor'k
Kälbäcär
Istisu
Piçänis
Xocavänd
Beylägan
Füzuli
Horadiz
Ider
Qubadli
Zangilan
Ordubad
Culfa
Meghri
Aläjüjeh
Ağdam
Ağcabädi
Bärdä
Tärtär
Ağdäräk
Göygöl
Şäki
Oğuz
Qäbälä
Qax
Zaqatala
Balakän
Gäncä
Xanlar
Daşkäsän
Gädäbäy
Qazax
Tovuz
Dällär
Qaracämirli
Şämkir
Dilijan
Vanadzor
Gyumri
Spitak
Ijevan
Tumanyan
Alaverdi
Odzun
Step'anavan
Ashots'k
Amasia
Tashir
Akhalkalaki
Ninotsminda
Dmanisi
Bolnisi
Marneuli
Tsalka
Tel'ritsqaro
Manglisi
Akhaltsikhe
Abastumani
Bakuriani
Borjomi
Khashuri
Gori
Kaspi
Akhalgori
Ts'khinvali
Java
Chiat'ura
Sachkhere
Tqibuli
K'ut'aisi
Samtredia
Zestap'oni
Baghdadi
Senaki
Khoni
Poti
Ozurgeti
Ajaria
Khulo
Vale
Posof
Ardahan
Çıldır
Doğuyolu
Hanak
Kurtkale
Kartsakhi
Akhalk'alaki
Suida
Akarsu
Şavşat
Çamlıçatak
Haskö
Yiğitkonağı
Arpaçay
Göle
Boğazköy
Kars
Sarıkamış
Şenkaya
Selim
Pazarcık
Kurudere
Digor
Kocaköy
Karakurt
Kağizman
Akçay
Tuzluca
Iğdır
Aralık
Eleşkirt
Karaköse
Taşlıçay
Hamur
Diyadin
Doğubayazıt
Patnos
Malazgirt
Erciş
Bulanık
Sarısu
Muradiye
Çaldıran
Mäkü
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Meghri
Aläjüjeh
Şärur
Şahbuz
Kapan
Qubadli
Zangilan
Laçın
Goris
Sisian
Kajaran
Vayk
Angegnadzor
Yeghegnadzor
Jermuk
Martuni
Vardenis
Sor'k
Kälbäcär
Istisu
Piçänis
Xankändi
Xocavänd
Şuşa
Füzuli
Horadiz
Ider
Beylägan
Lerik
Astara
Cälilabad
Masallı
Yevlax
Mingäçevir
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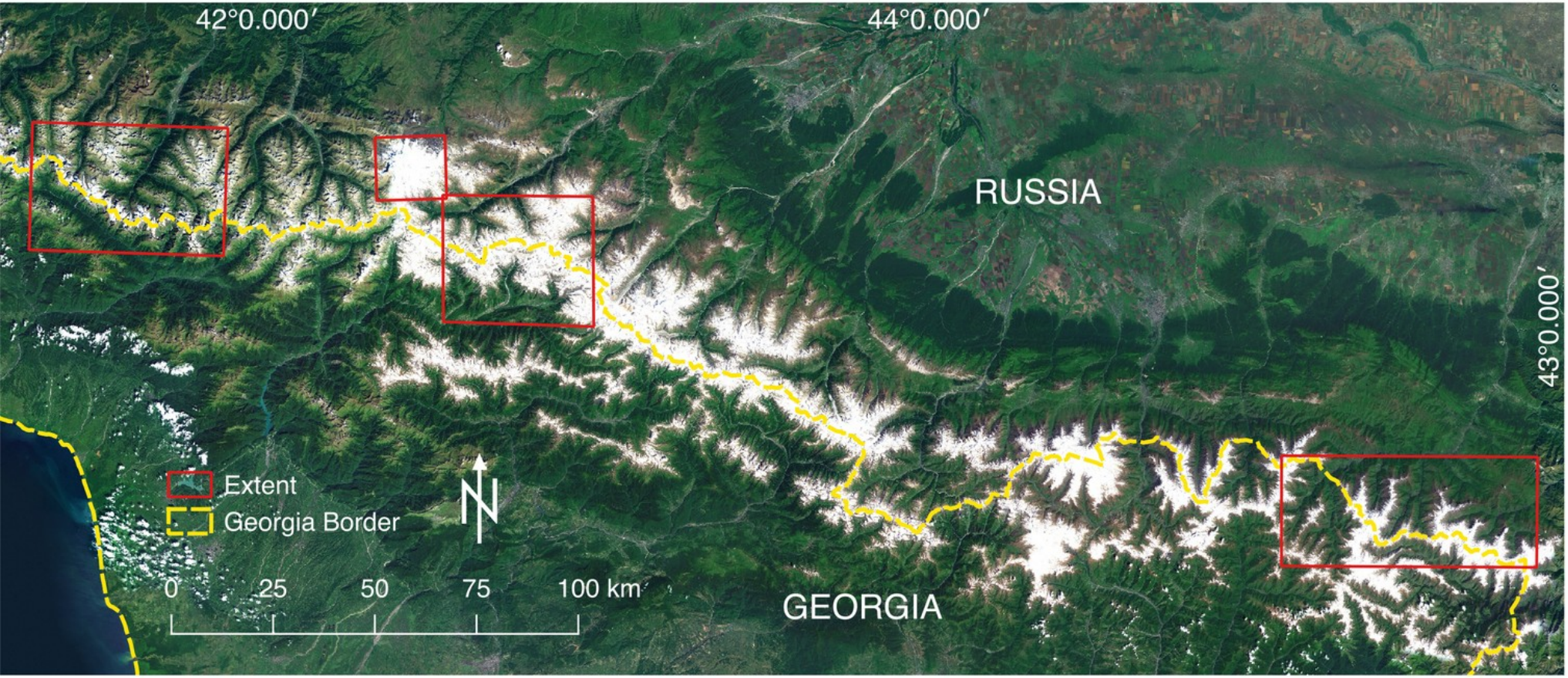
Kür (Kura)
Aras
Terek
Kuma
Kubani
Baksan
Malka
Sunzha
Argun
Aragats
Ararat
Sevan
Ararat
Mäkü
Patnos
Malazgirt
Erciş
Karaköse
Doğubayazıt
Eleşkirt
Kağizman
Sarıkamış
Ardahan
Akçay
Tuzluca
Iğdır
Aralık
Sarur
Şahbuz
Kapan
Qubadli
Zangilan
Laçın
Goris
Sisian
Kajaran
Culfa
Ordubad

STUDY AREAS


42°0.000′
44°0.000′
43°0.000′
RUSSIA
GEORGIA
Extent
Georgia Border
N
0
25
50
75
100 km

AIM

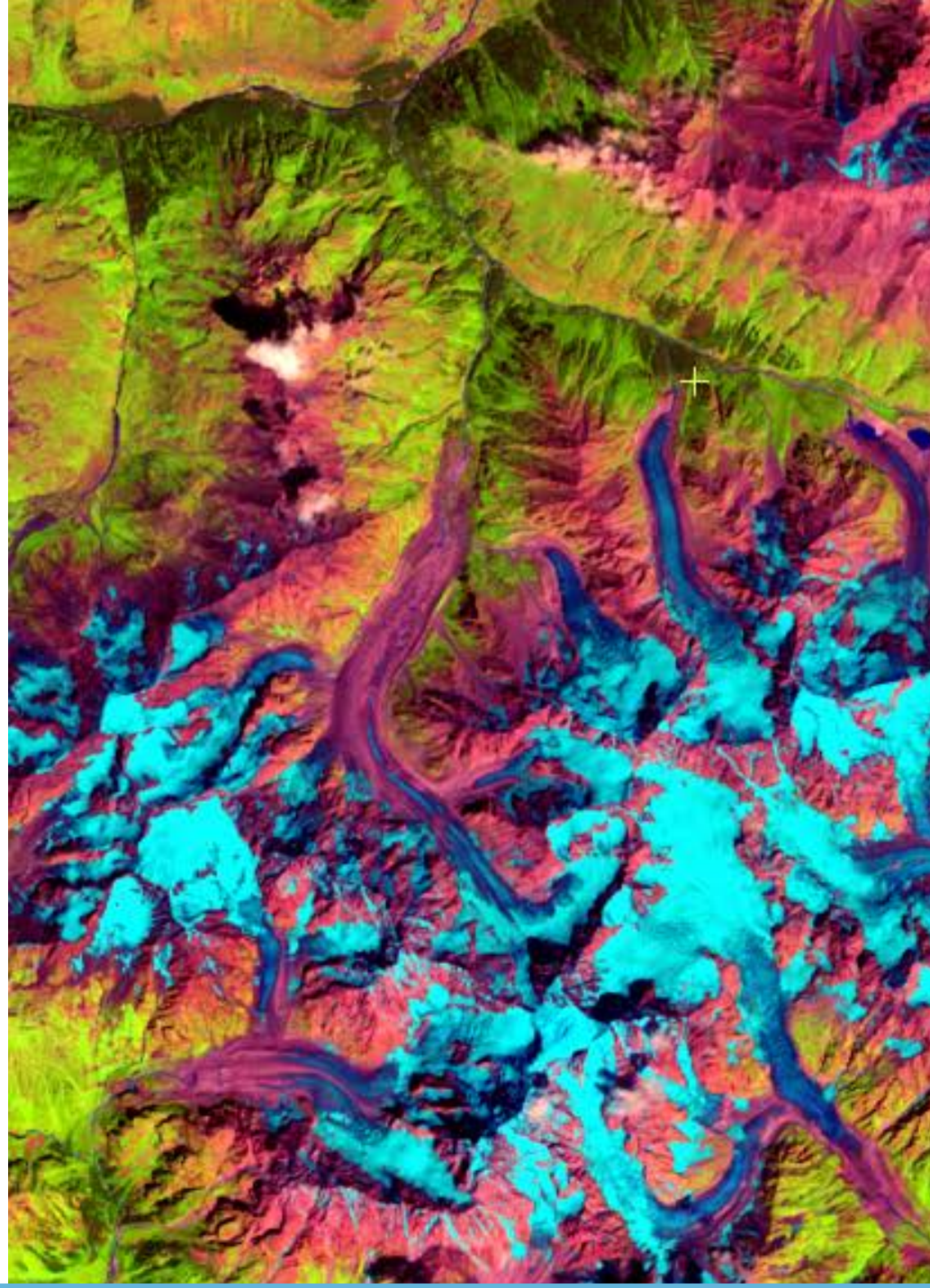
To compare and contrast the results of manual versus semi automatic methods of glacier digitization in the Caucasus mountain range

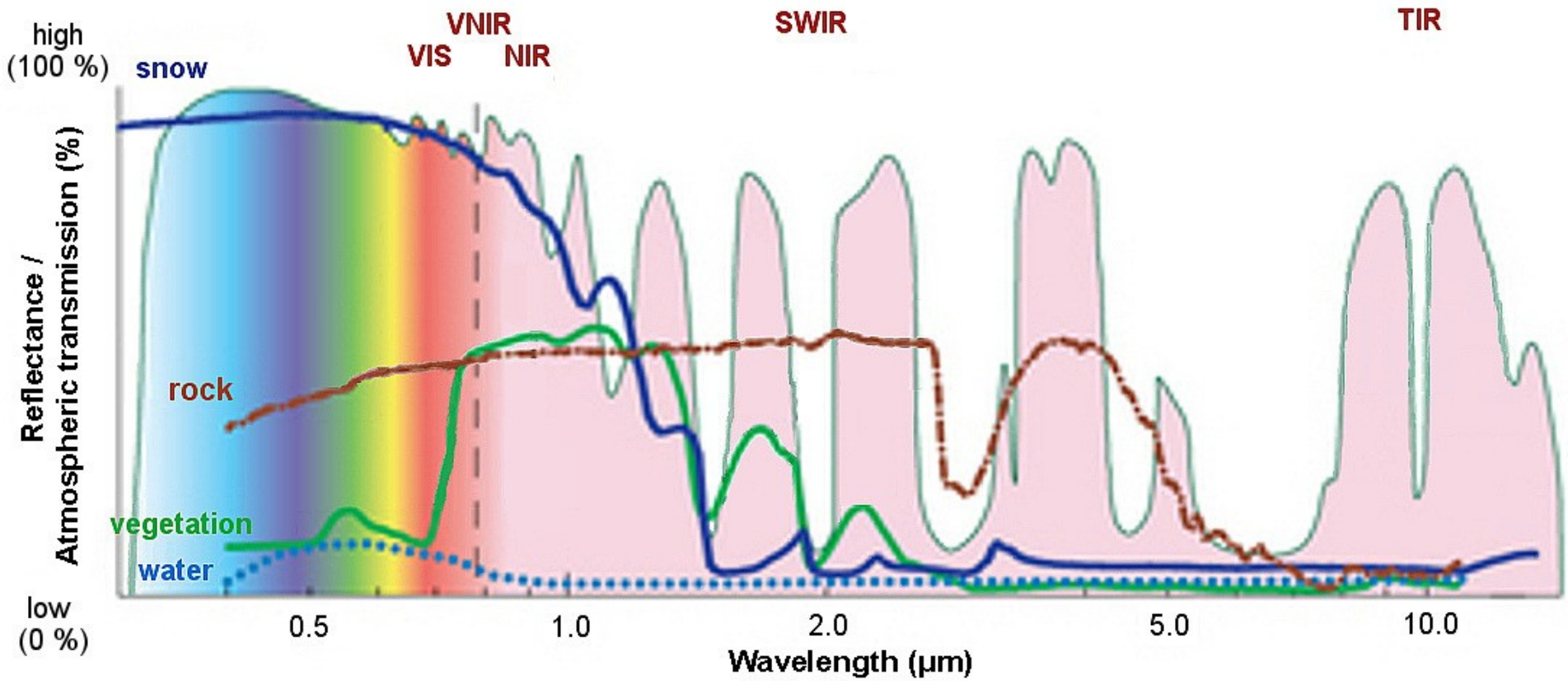
OBJECTIVES

- Examine available data and methods of glacier delineation
- Study the challenges of shadow, water and notably debris cover
- Select sample areas in the west, central and east Caucasus
- Determine optimum thresholds for band ratios of ice
- Compare glacier extents for manual, ratio, semi automatic methods
- Identify robust glacier outlines for the Caucasus region and methods which can be applied to other areas and for updates
- Compare outlines qualitatively and quantitatively

METHODS

BAND RATIO




high
(100 %)
low
(0 %)
Reflectance /
Atmospheric transmission (%)
snow
VNIR
VIS
NIR
SWIR
TIR
rock
vegetation
water
0.5
1.0
2.0
5.0
10.0
Wavelength (µm)

$$R_{red/SWIR} = DN_{red}/DN_{SWIR}$$

Paul et al. (2016)

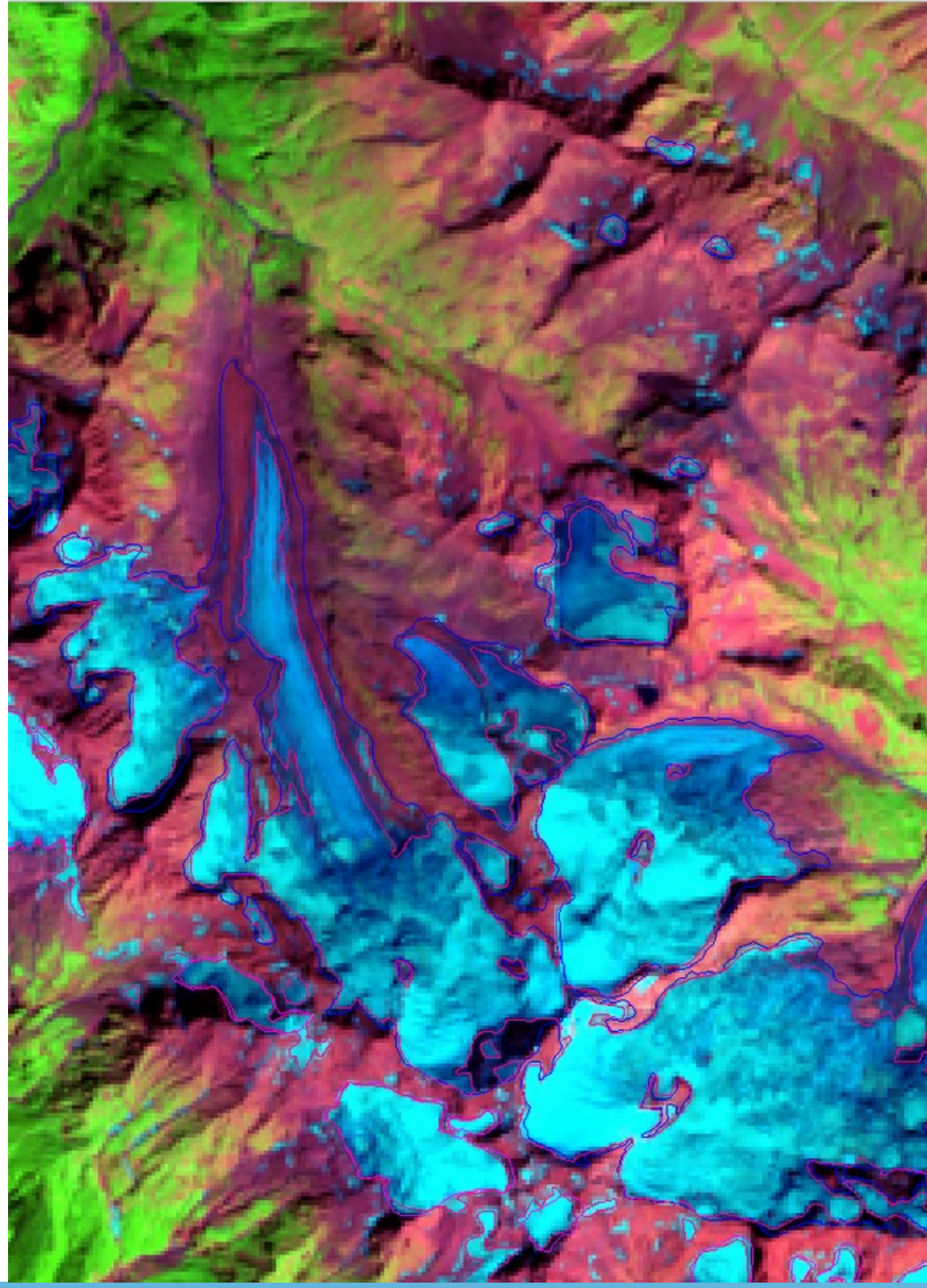
$$R_{panchromatic/SWIR} = DN_{panchromatic}/DN_{SWIR}$$

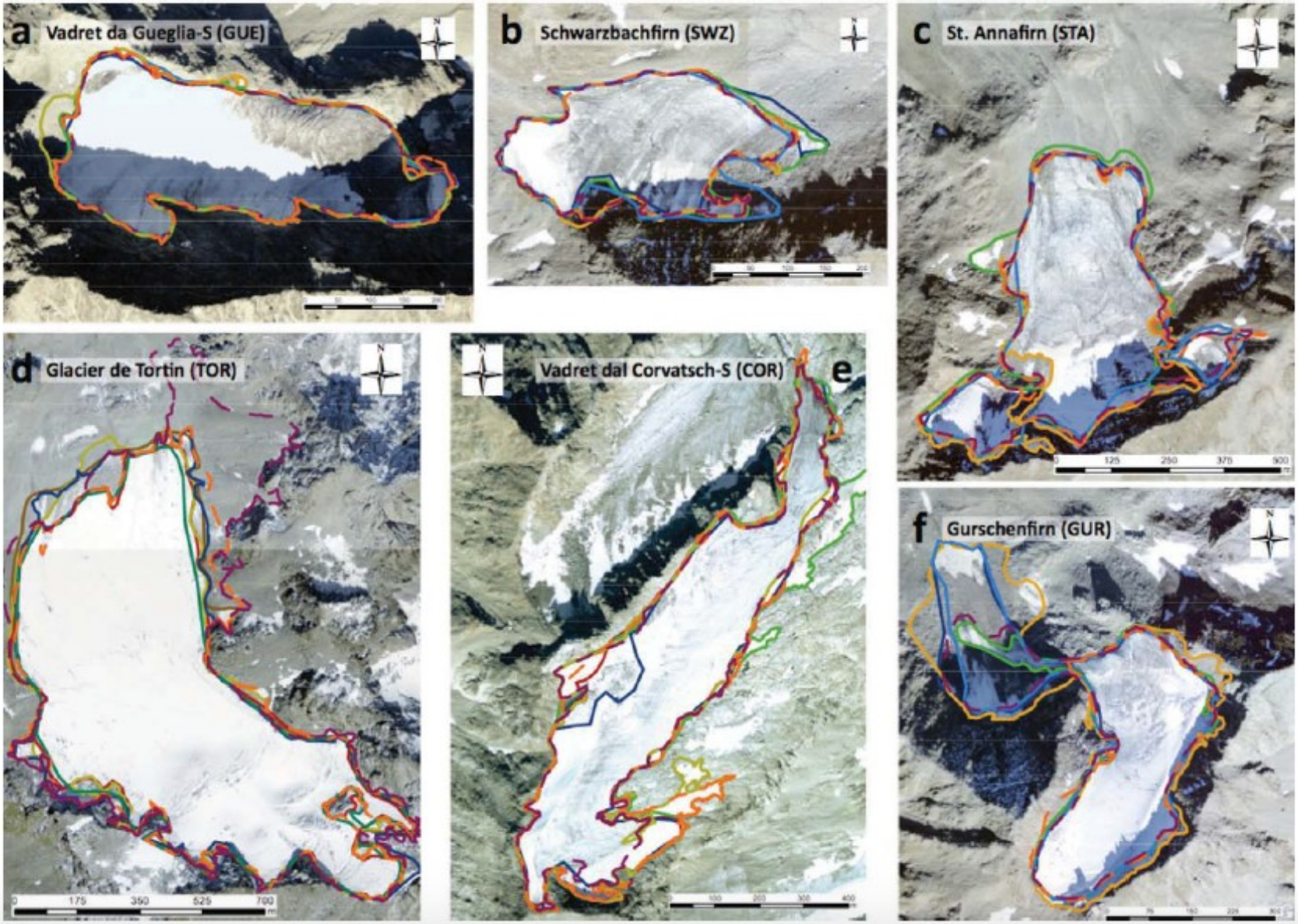
Alifu et al. (2016)

$$R_{TIR/(NIR/SWIR)} = DN_{TIR}/(DN_{NIR}/DN_{SWIR})$$

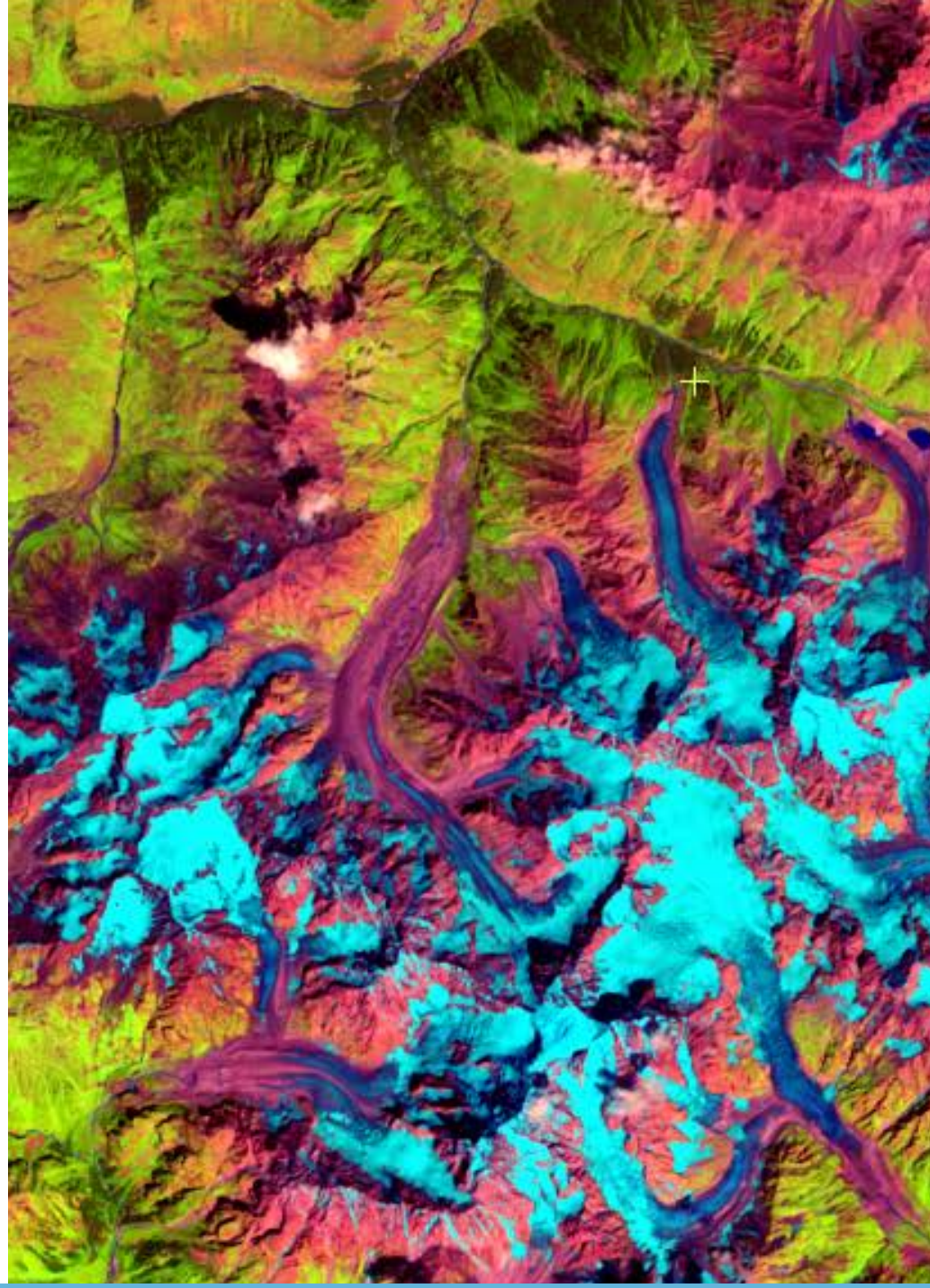
(where R is the ratio between bands and DN is the digital number (brightness value) of a pixel in the respective band.)

MANUAL OUTLINES

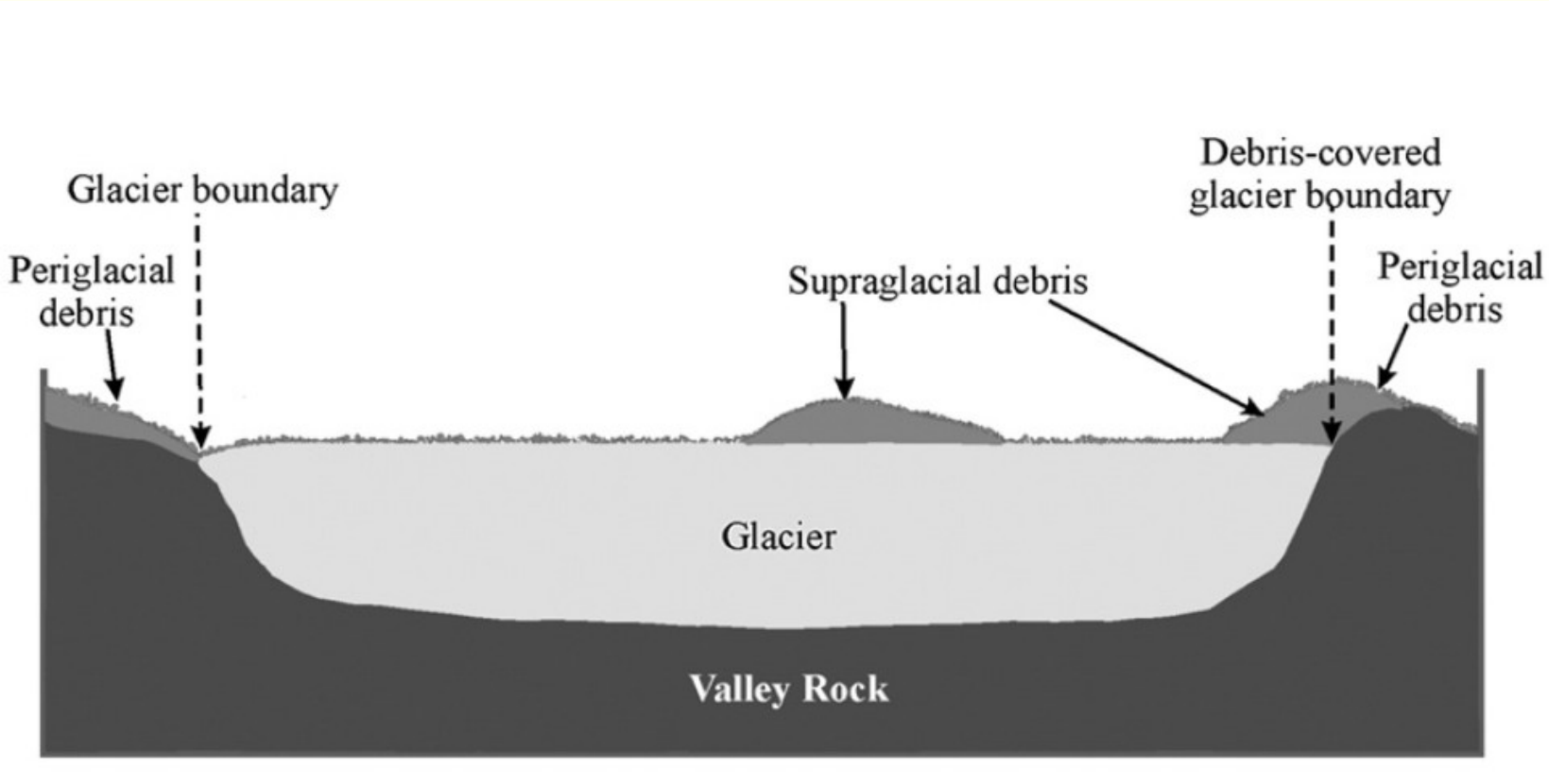


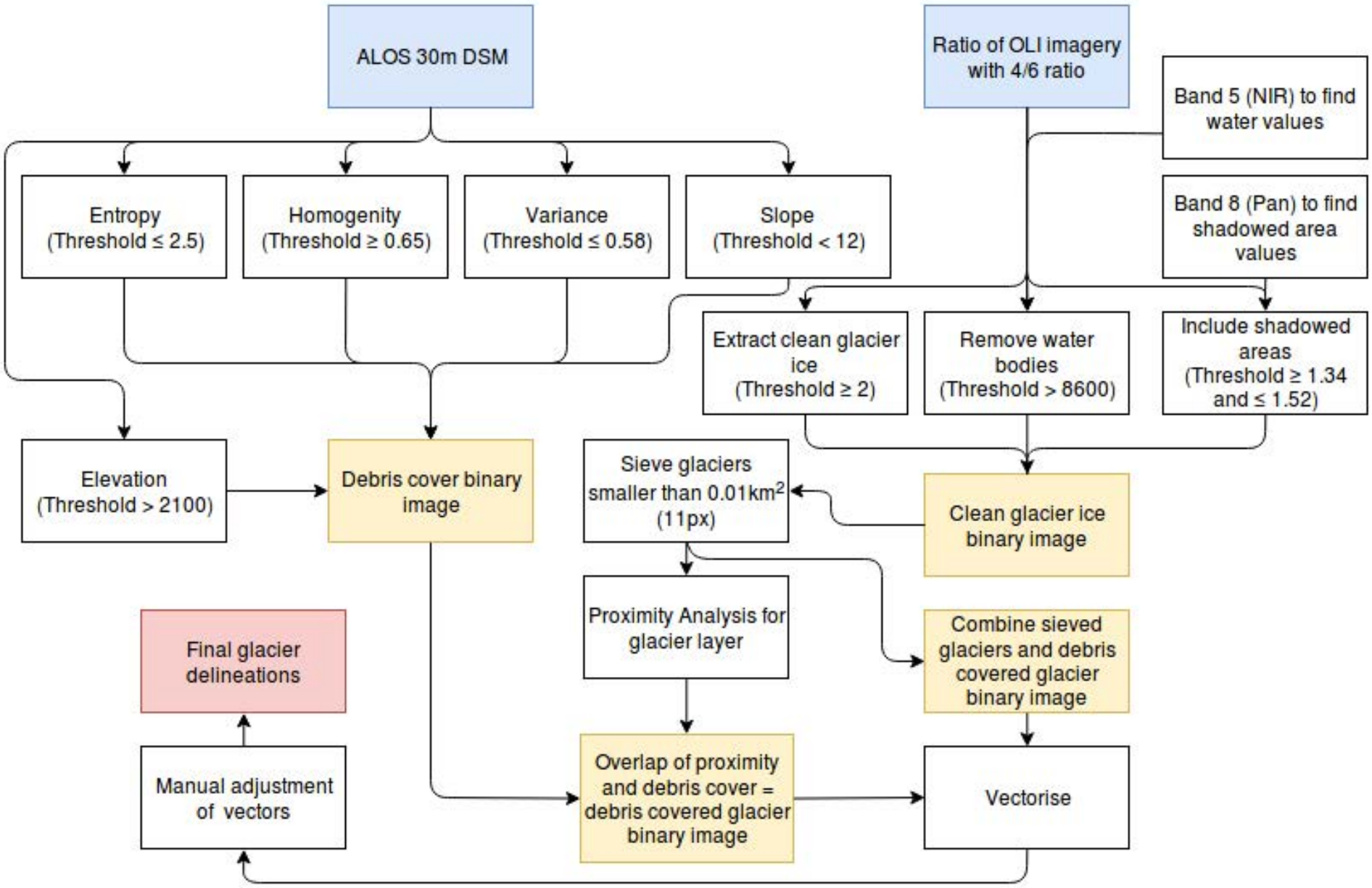

a Vadret da Gueglia-S (GUE)
b Schwarzbachfirn (SWZ)
c St. Annafirn (STA)
d Glacier de Tortin (TOR)
Vadret dal Corvatsch-S (COR) e
f Gurschenfirn (GUR)

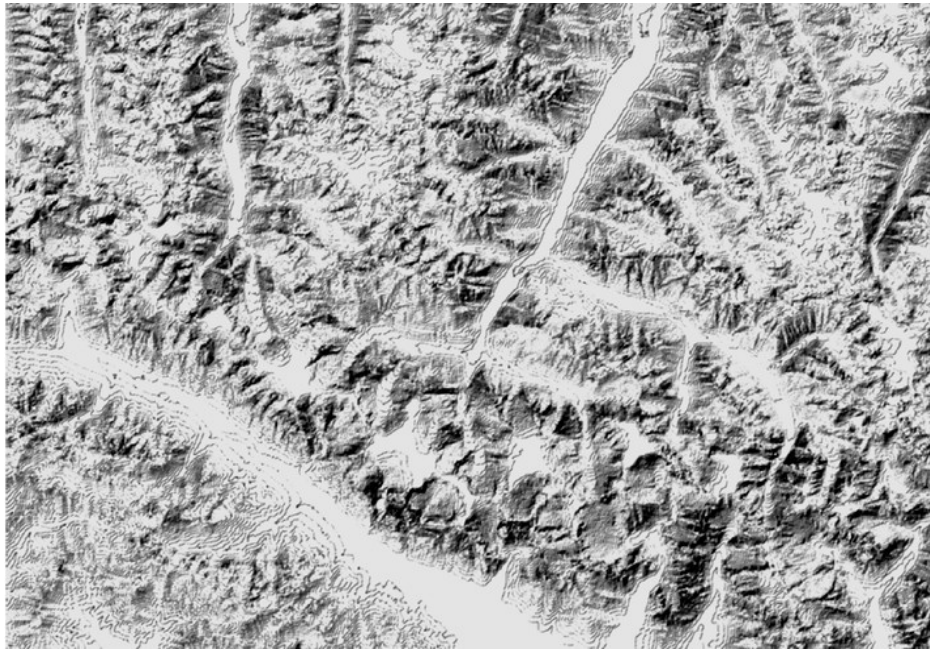
SEMI AUTOMATIC

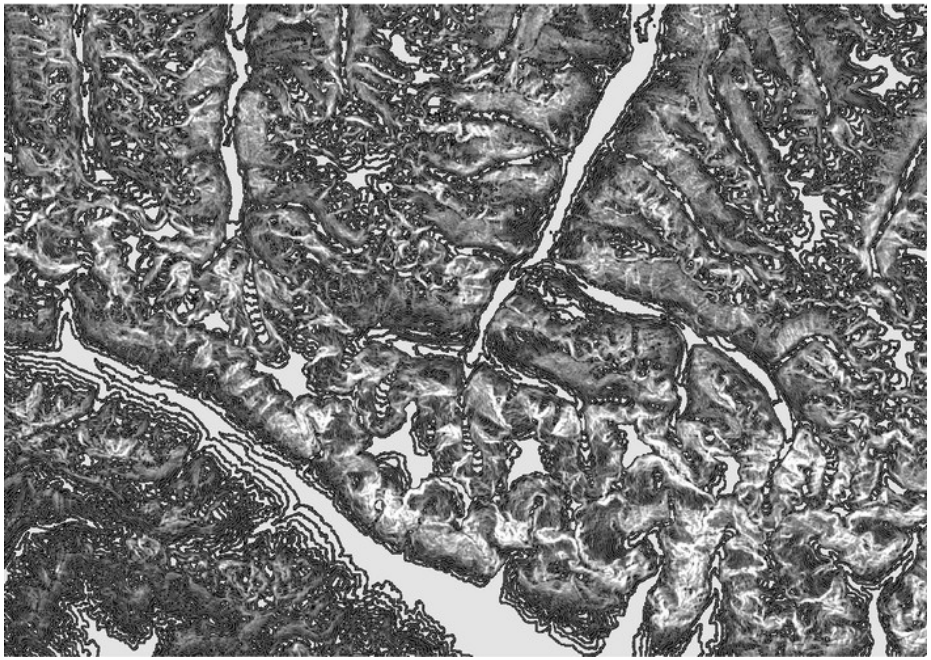


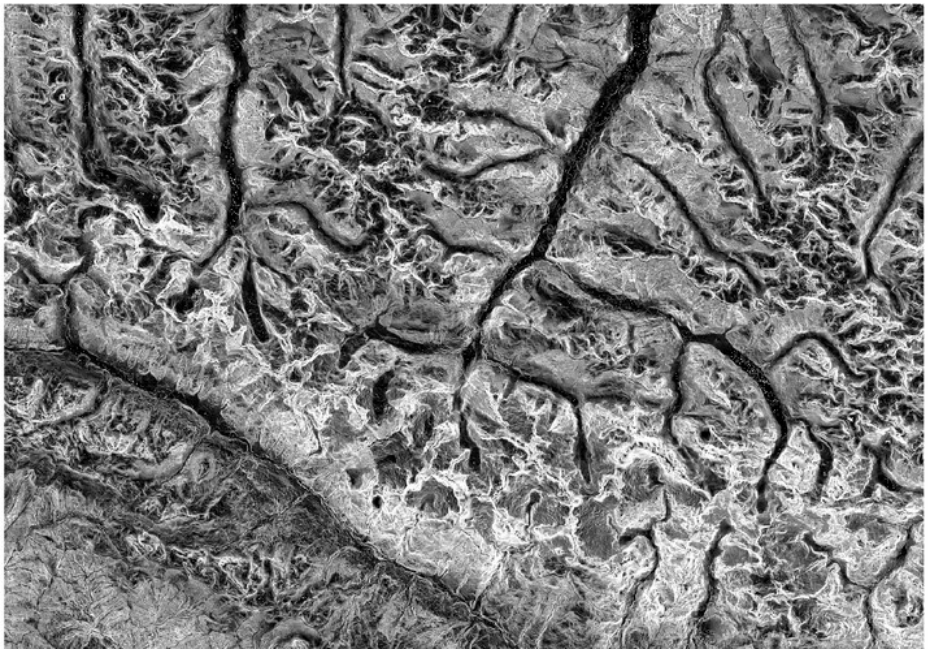
DEBRIS COVER

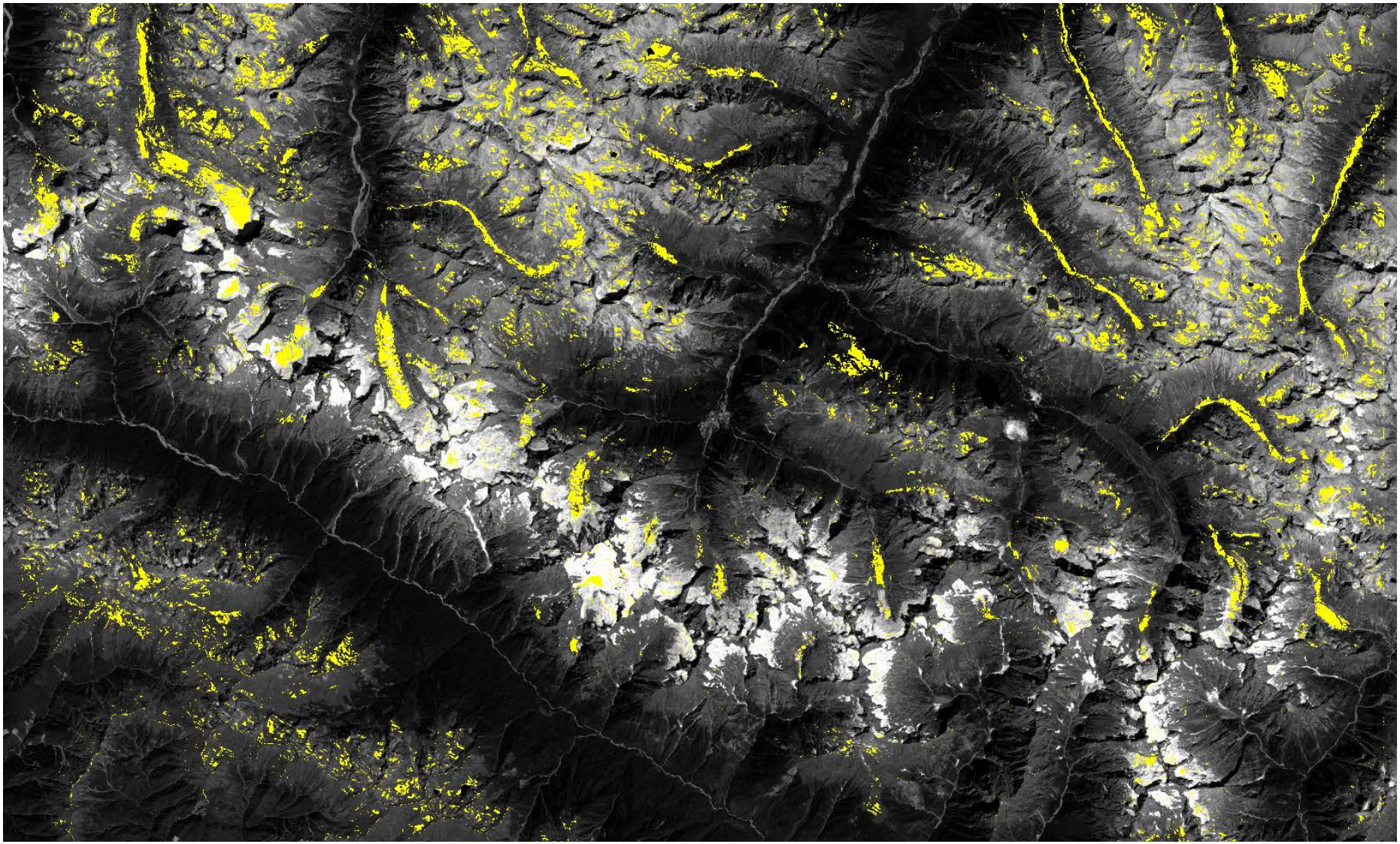


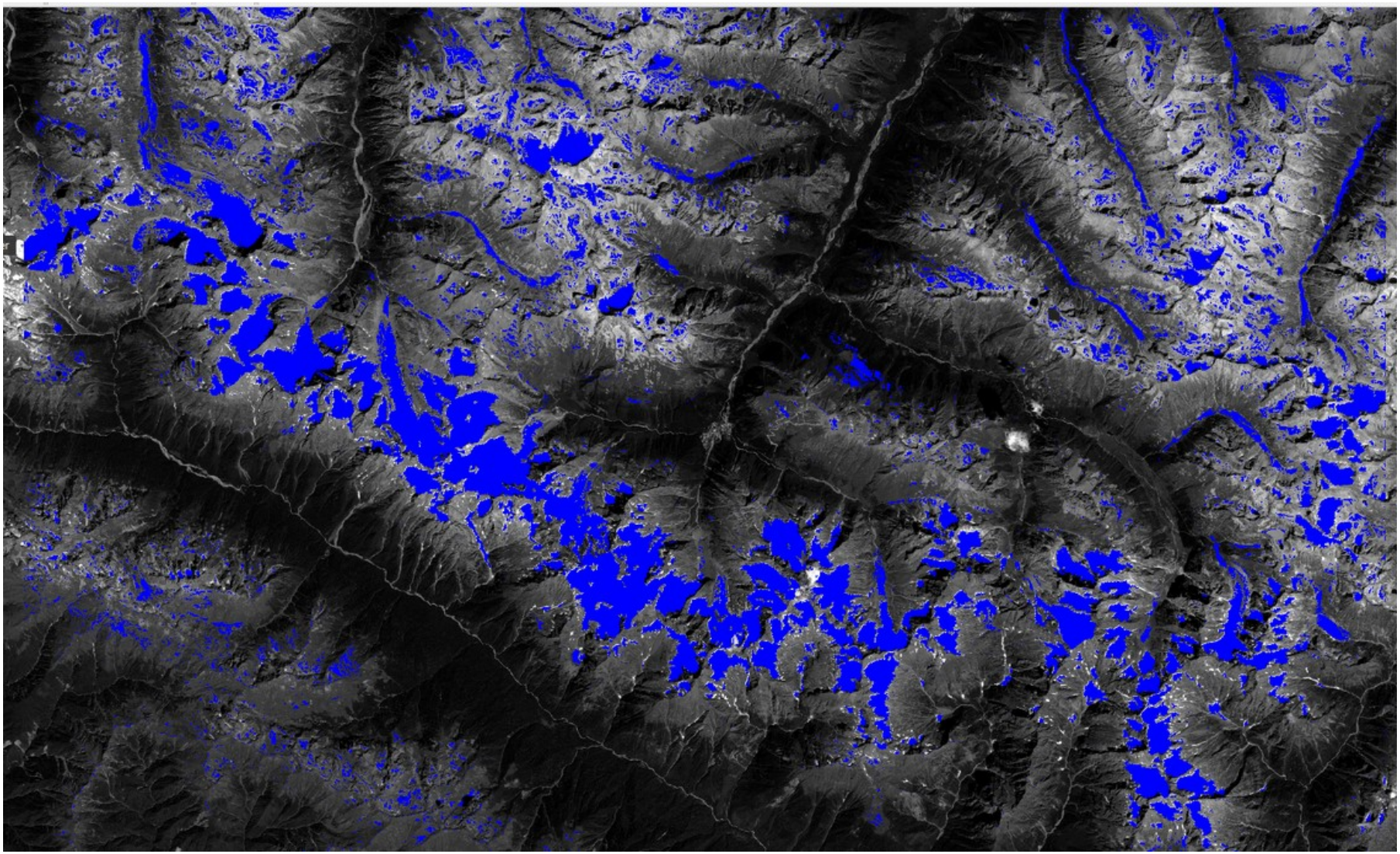

ALOS 30m DSM
Ratio of OLI imagery with 4/6 ratio
Band 5 (NIR) to find water values
Entropy (Threshold ≤ 2.5)
Homogenity (Threshold ≥ 0.65)
Variance (Threshold ≤ 0.58)
Slope (Threshold < 12)
Band 8 (Pan) to find shadowed area values
Extract clean glacier ice (Threshold ≥ 2)
Remove water bodies (Threshold > 8600)
Include shadowed areas (Threshold ≥ 1.34 and ≤ 1.52)
Elevation (Threshold > 2100)
Debris cover binary image
Sieve glaciers smaller than 0.01km2 (11px)
Clean glacier ice binary image
Proximity Analysis for glacier layer
Combine sieved glaciers and debris covered glacier binary image
Final glacier delineations
Manual adjustment of vectors
Overlap of proximity and debris cover = debris covered glacier binary image
Vectorise

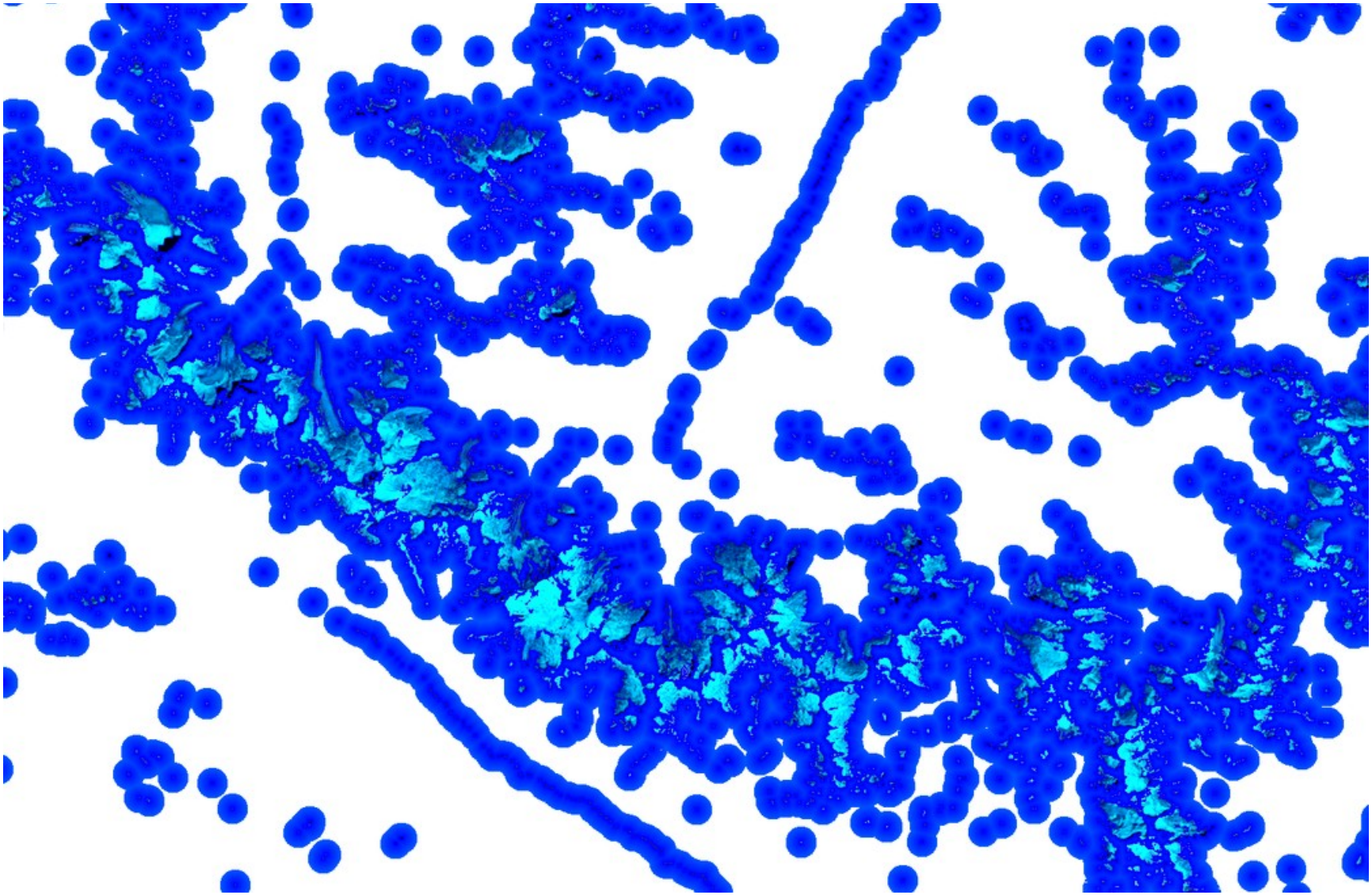


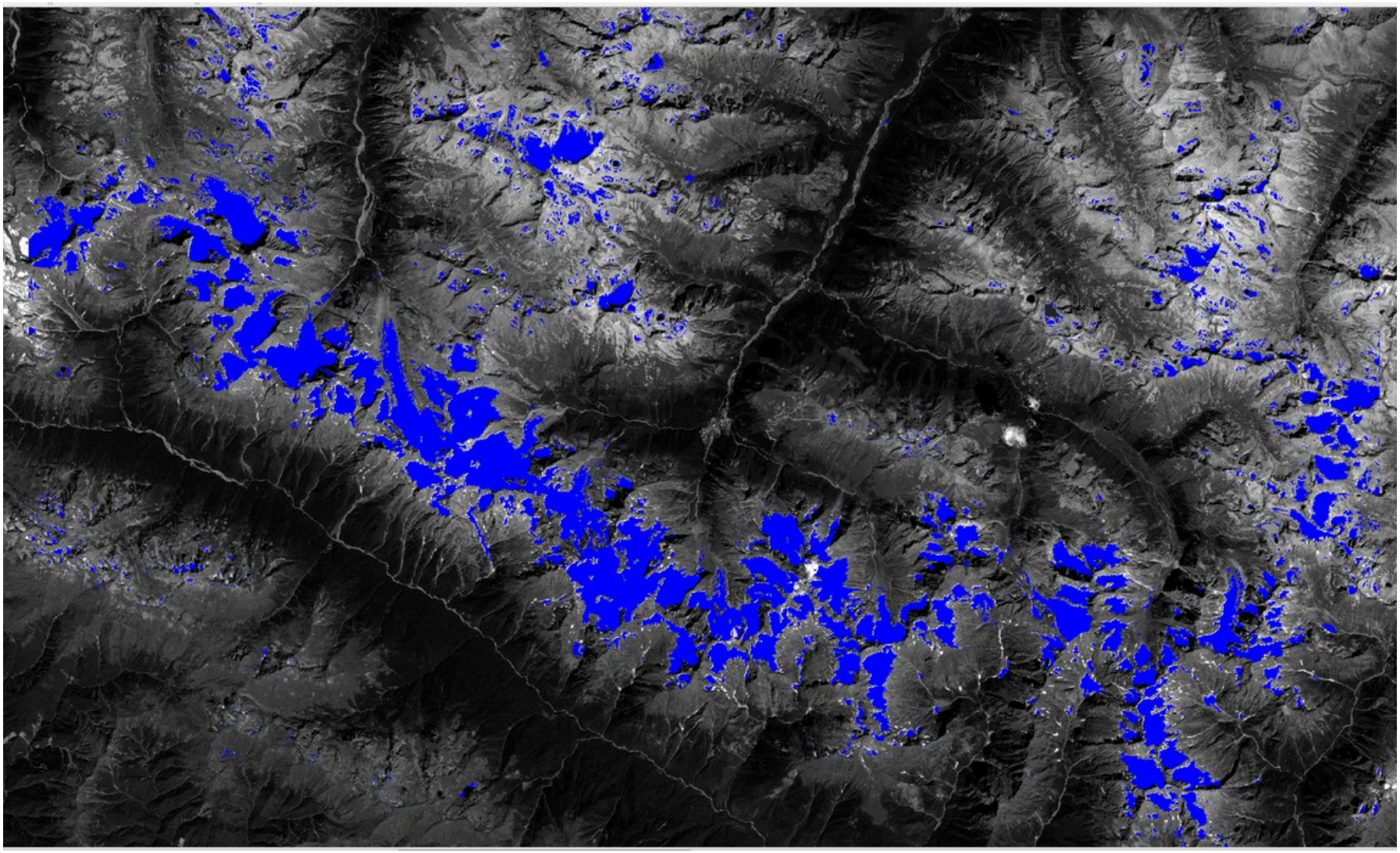


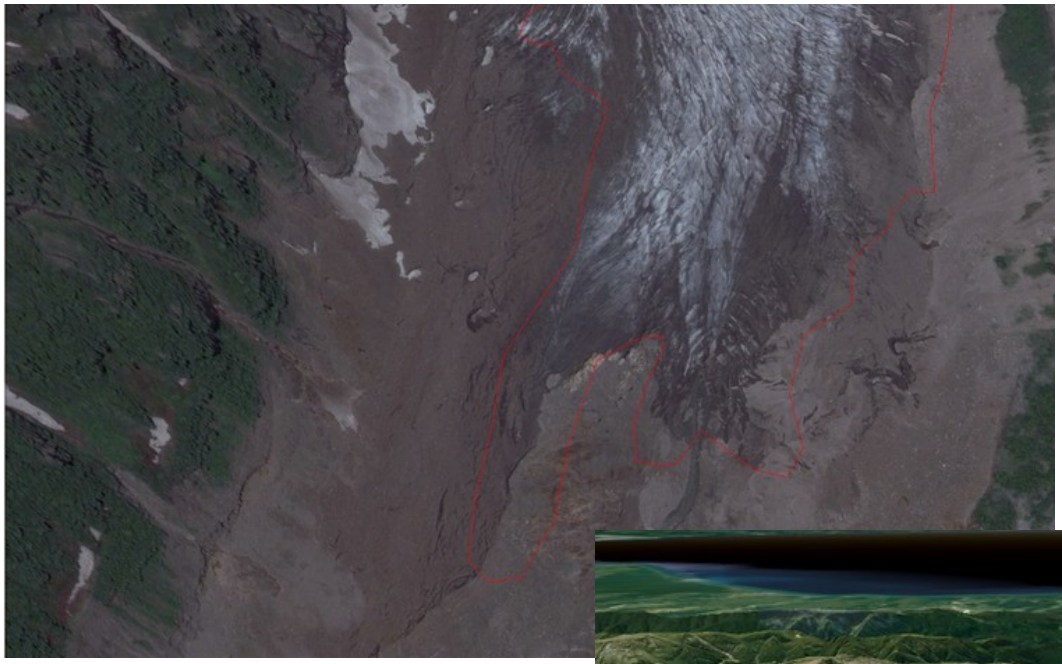


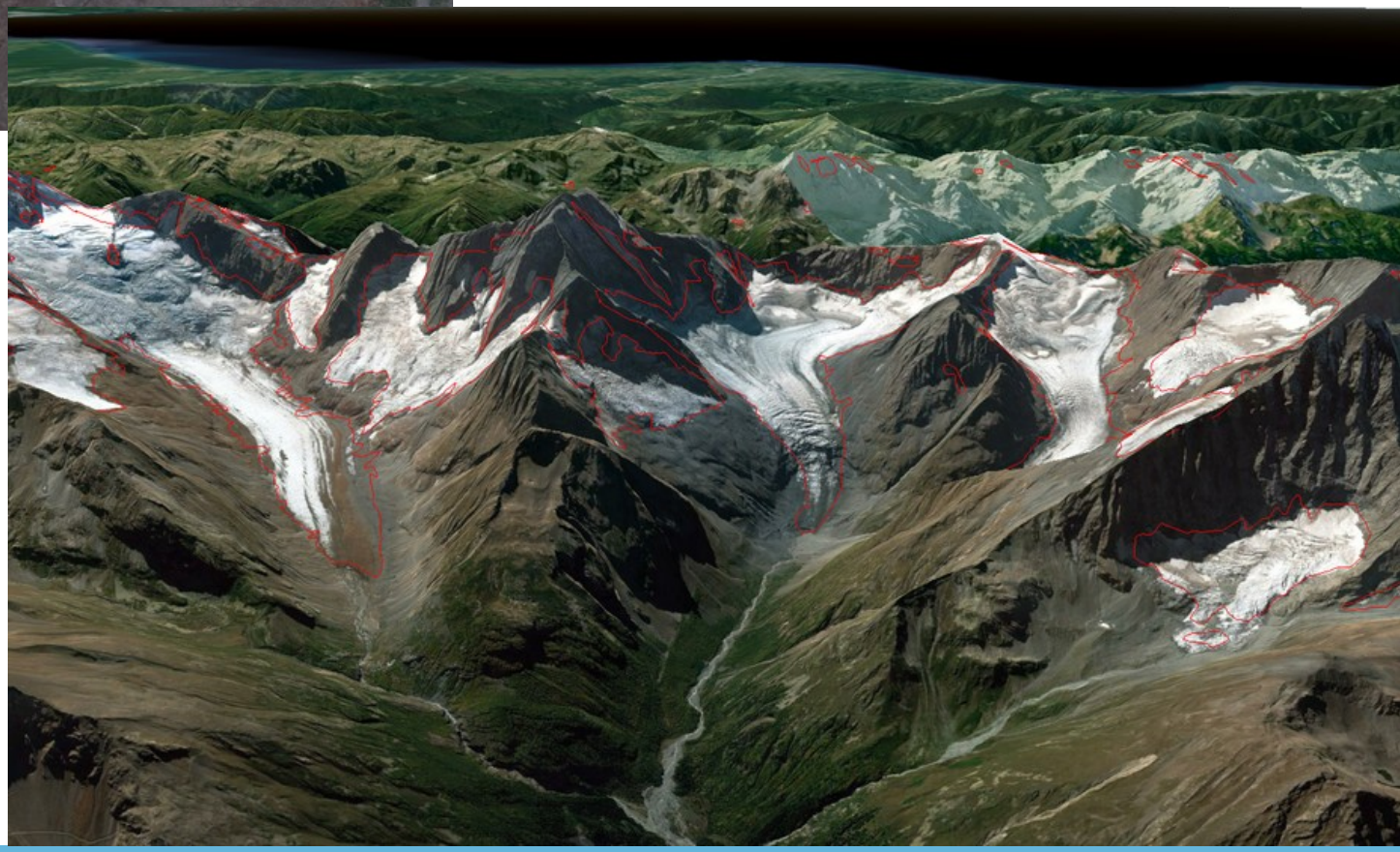




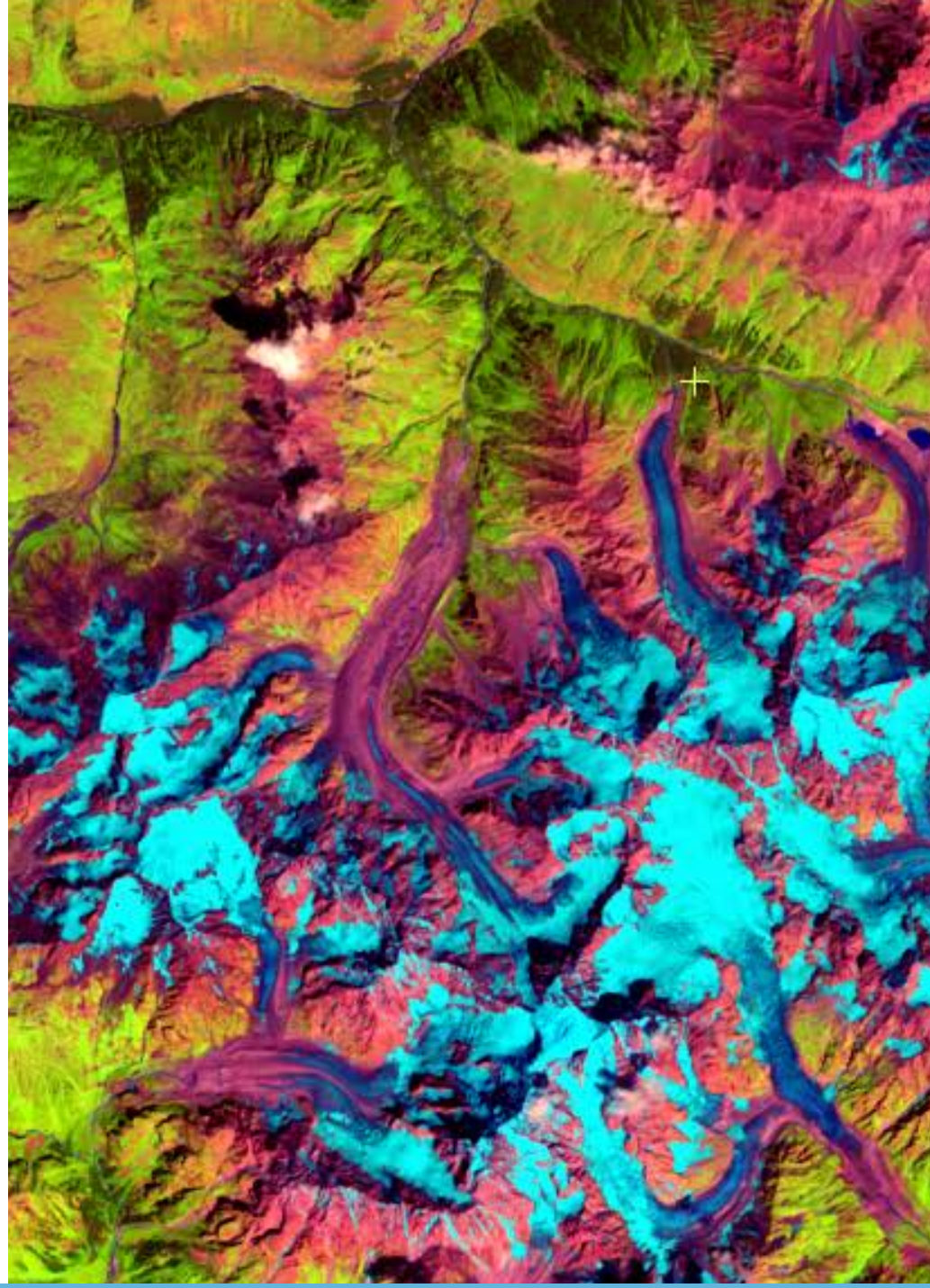








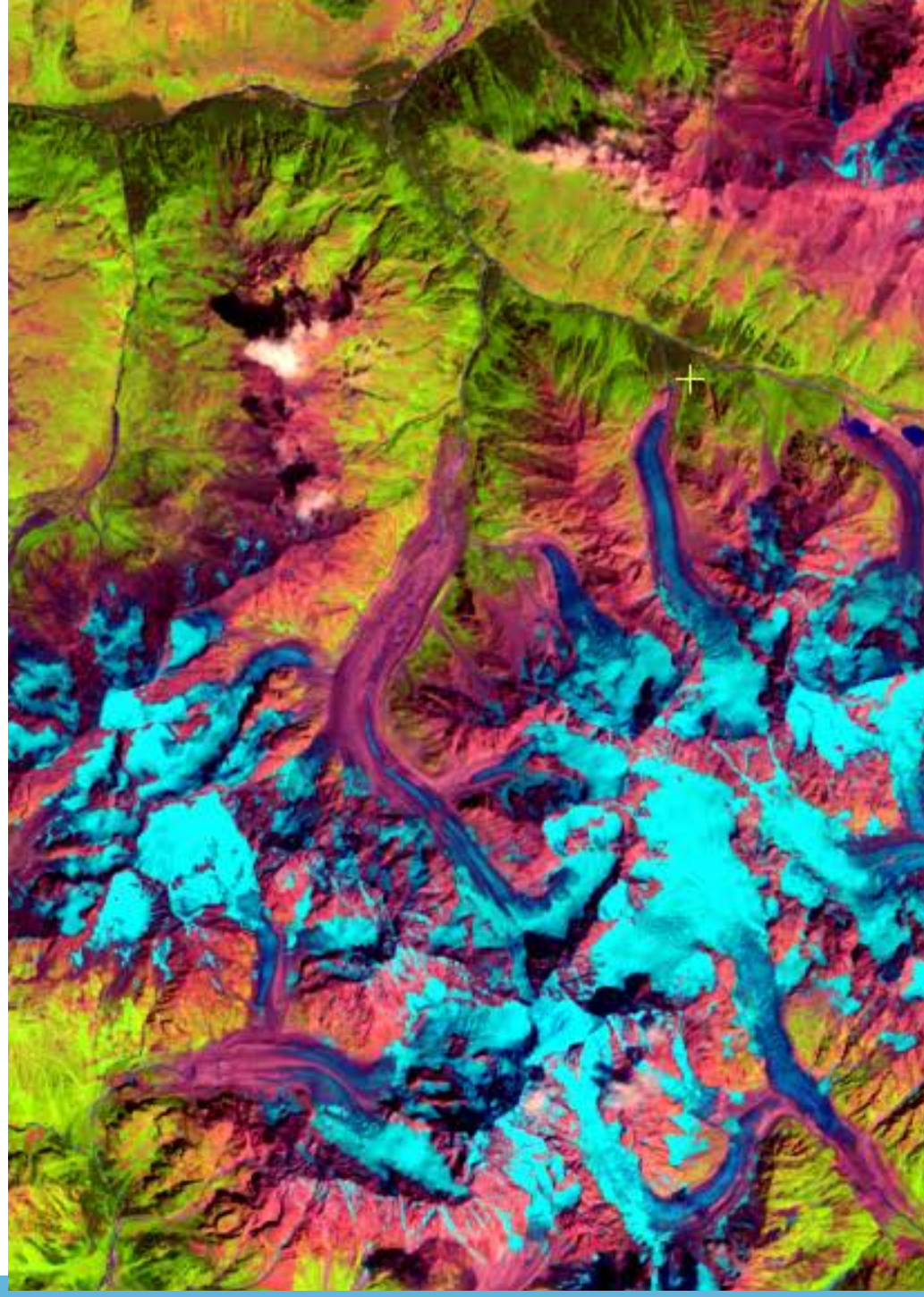
ASSESSING ACCURACY



		Ground Truth	
		Positives	Negatives
Classification Results	Positives	True Positive	False Positive
	Negatives	False Negative	True Negative

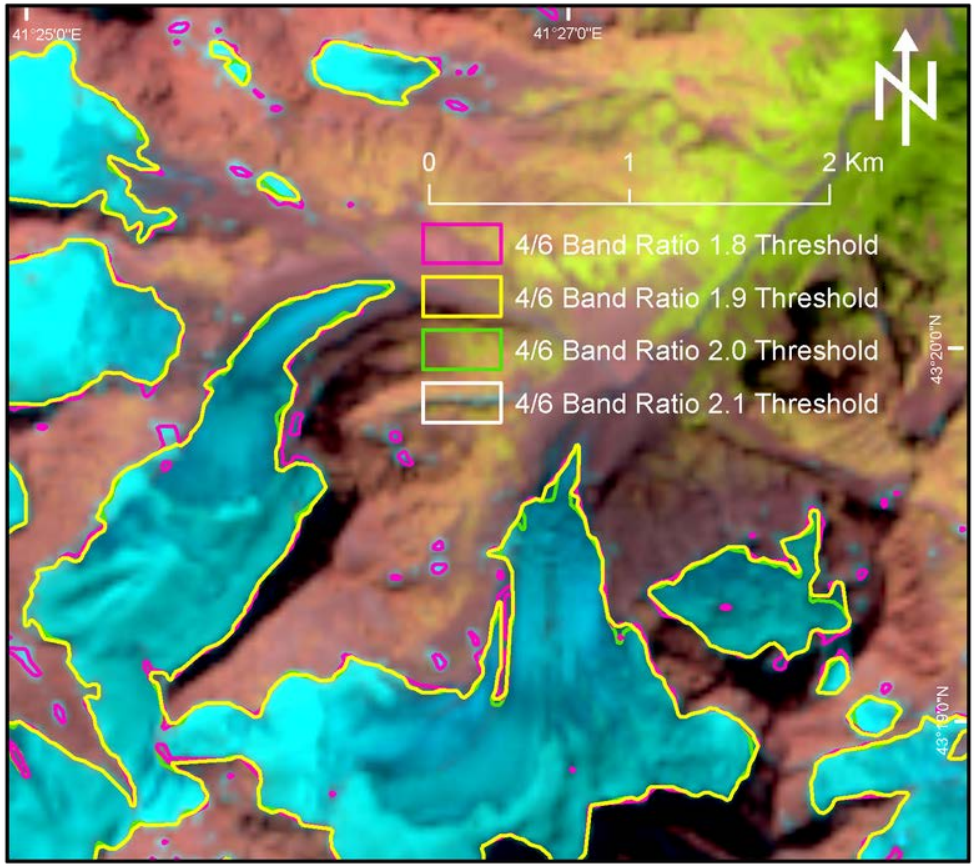
CONFUSION MATRIX

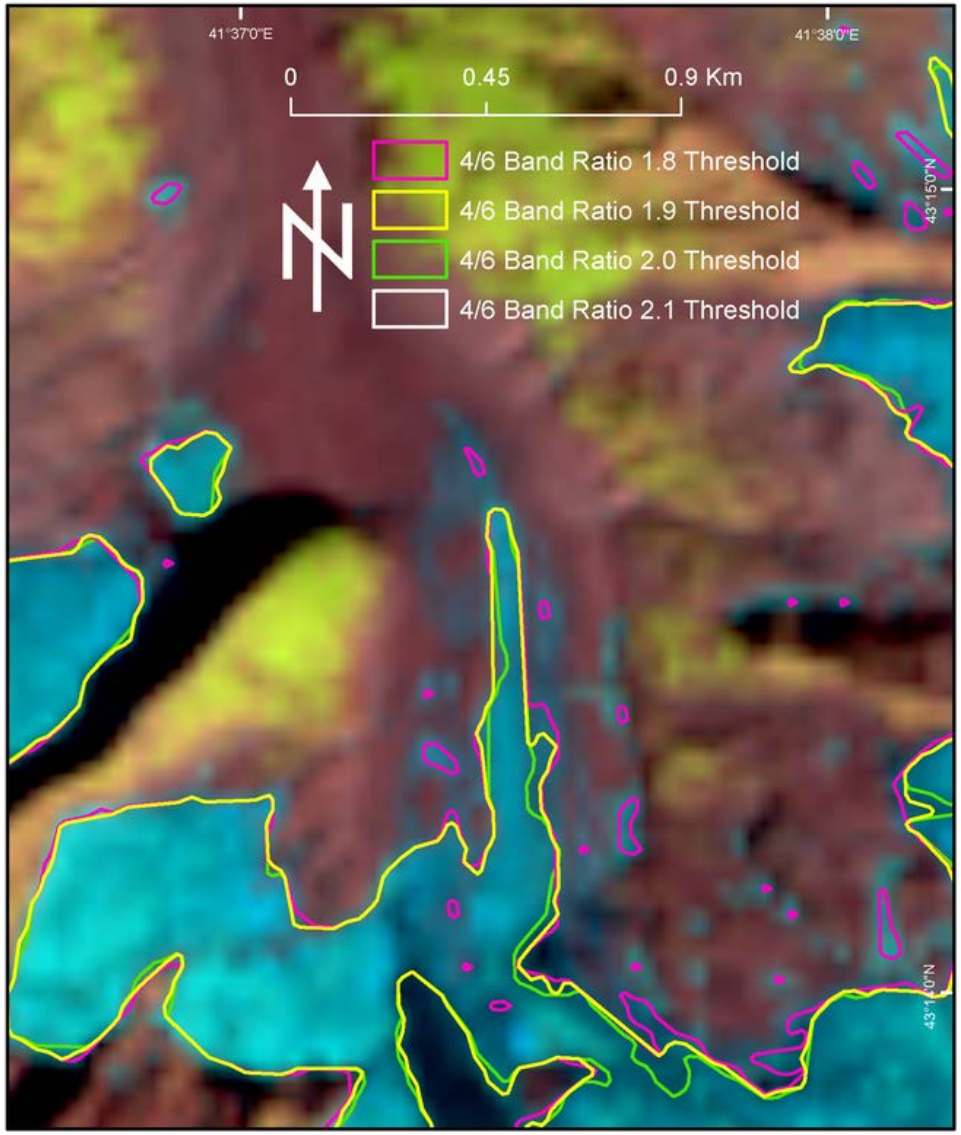
BUFFERS



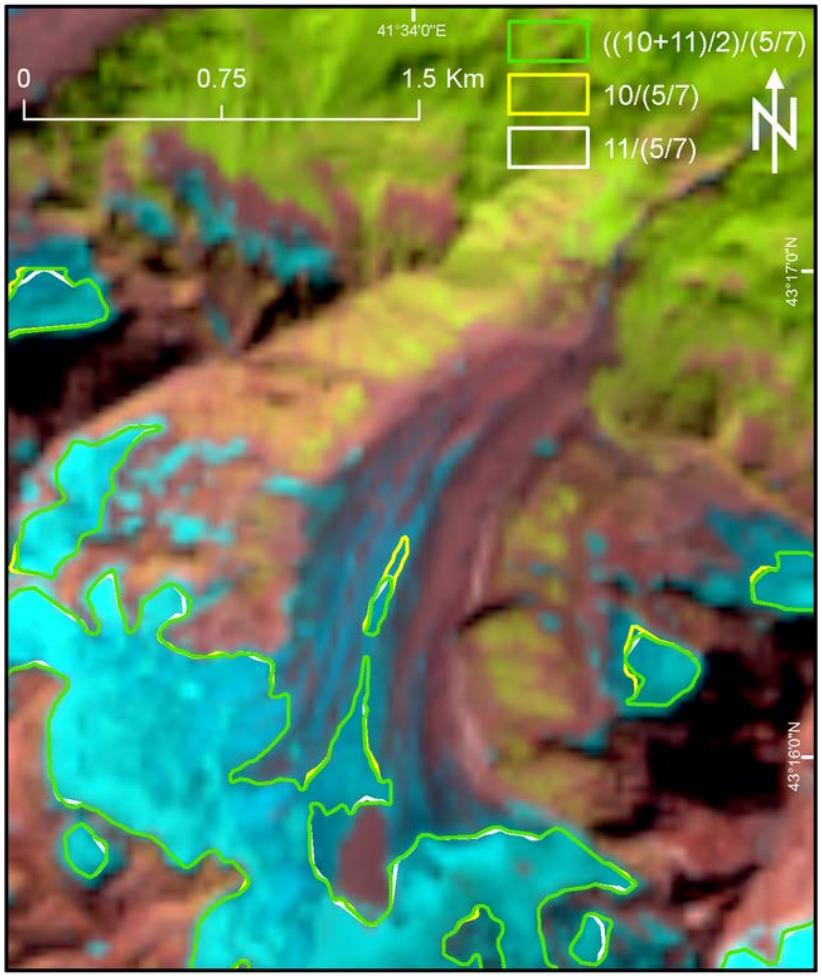
QUANTITATIVE RESULTS

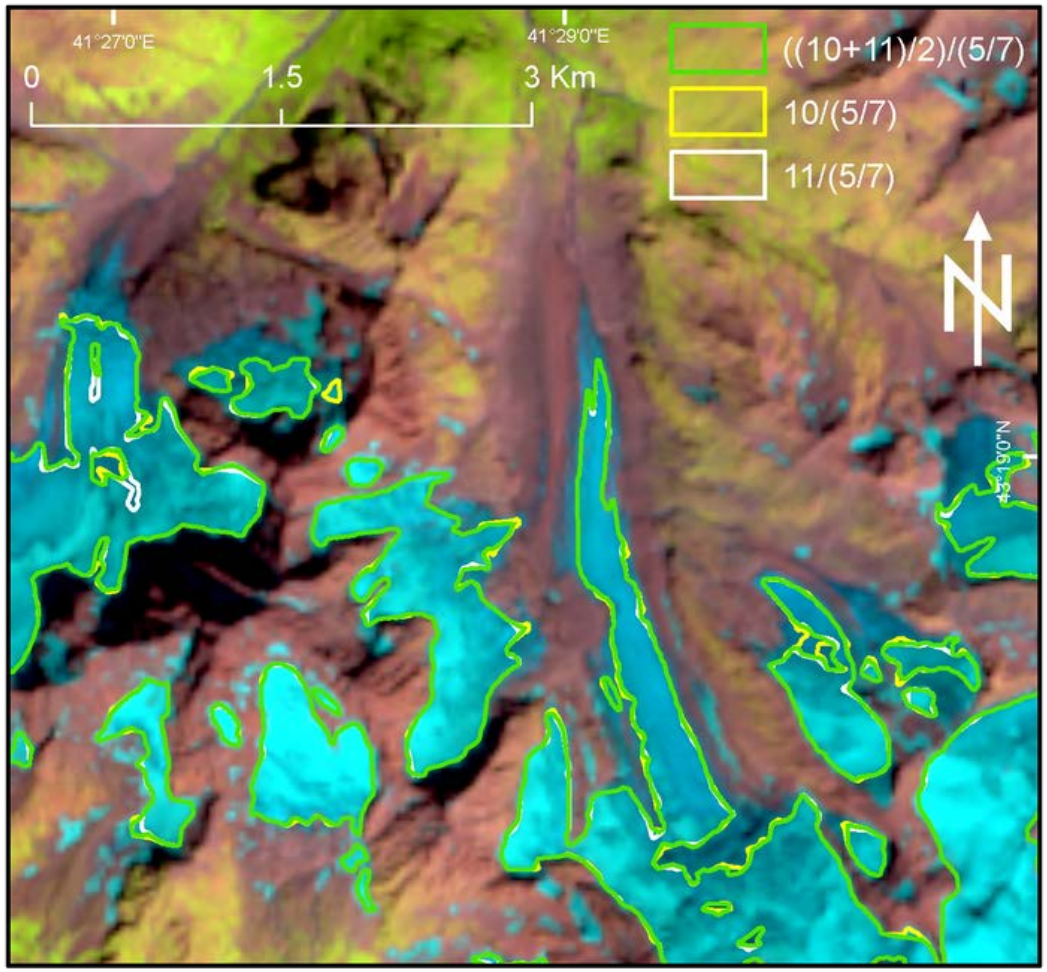
THRESHOLDS


41°25'0"E
41°27'0"E
0
1
2 Km
4/6 Band Ratio 1.8 Threshold
4/6 Band Ratio 1.9 Threshold
4/6 Band Ratio 2.0 Threshold
4/6 Band Ratio 2.1 Threshold
43°20'0"N


41°37'0"E
41°38'0"E
0
0.45
0.9 Km
4/6 Band Ratio 1.8 Threshold
4/6 Band Ratio 1.9 Threshold
4/6 Band Ratio 2.0 Threshold
4/6 Band Ratio 2.1 Threshold
43°15'0"N

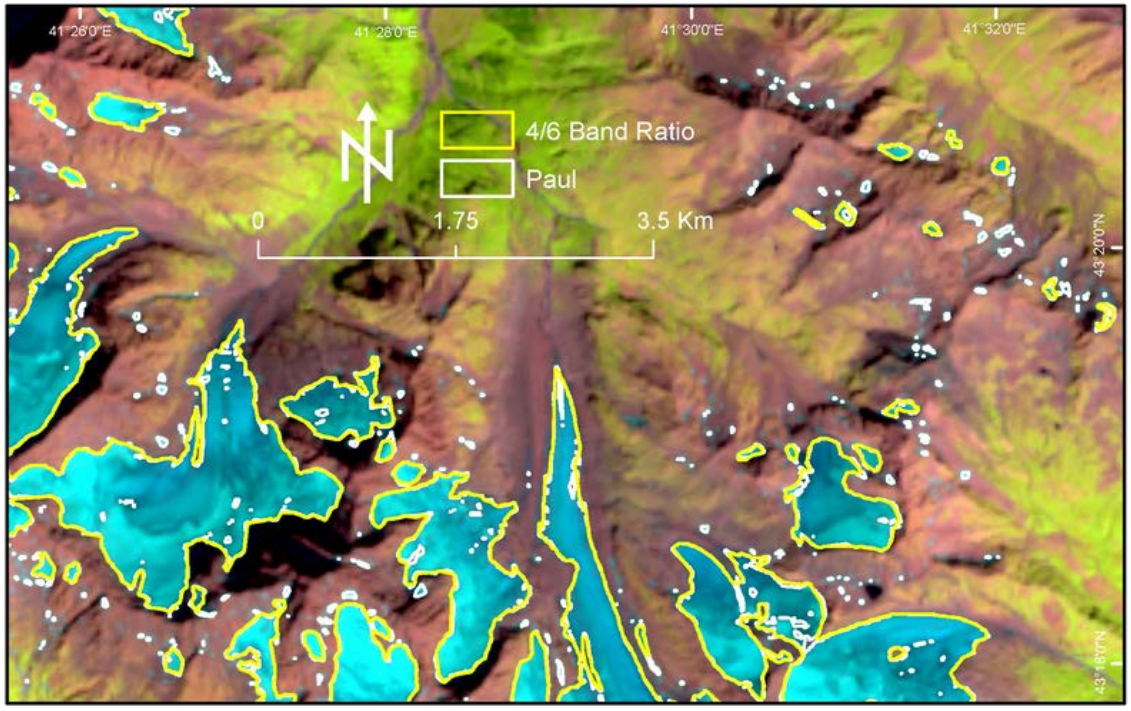
RTIR/(NIR/SWIR) = DNTIR/ (DNNIR/ DNSWIR)

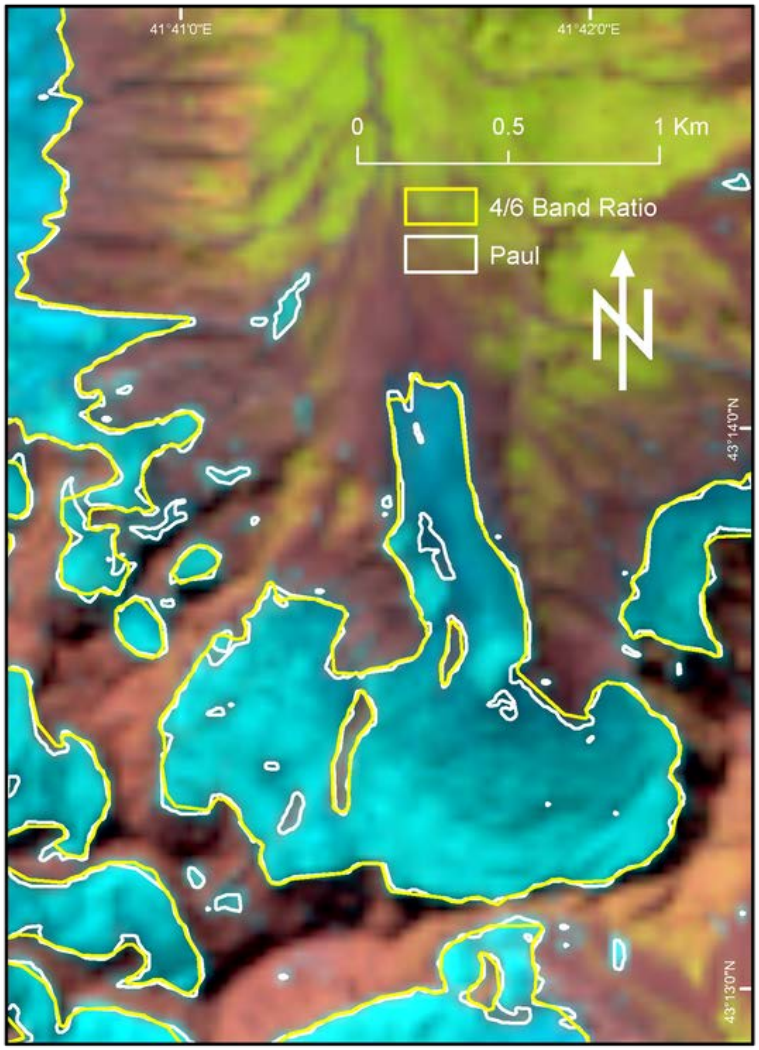




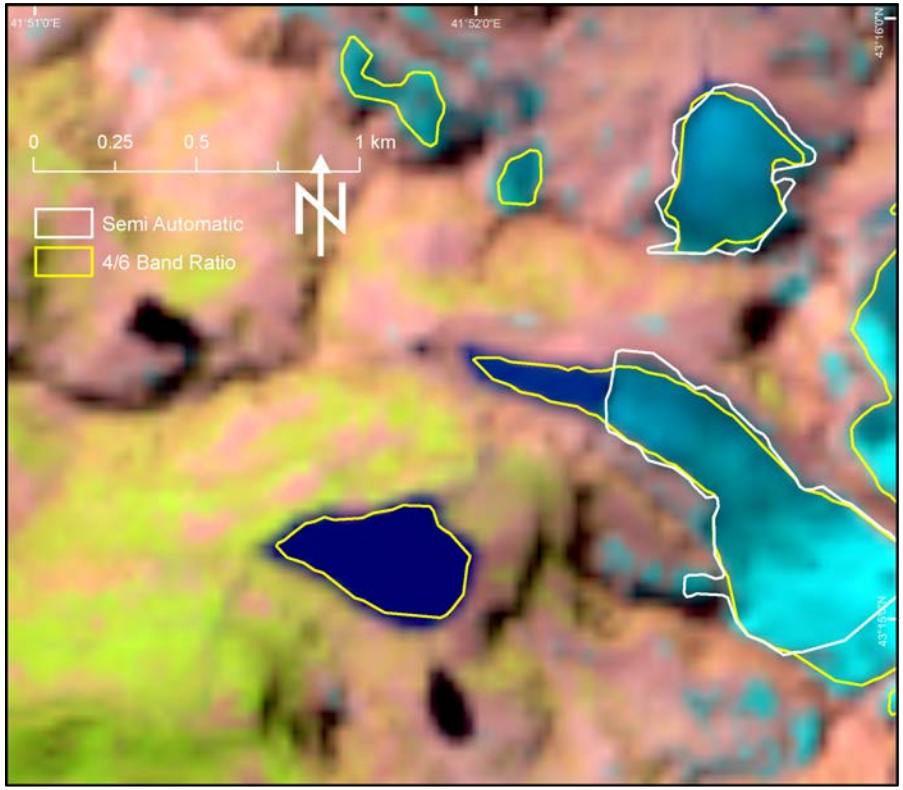
P A U L

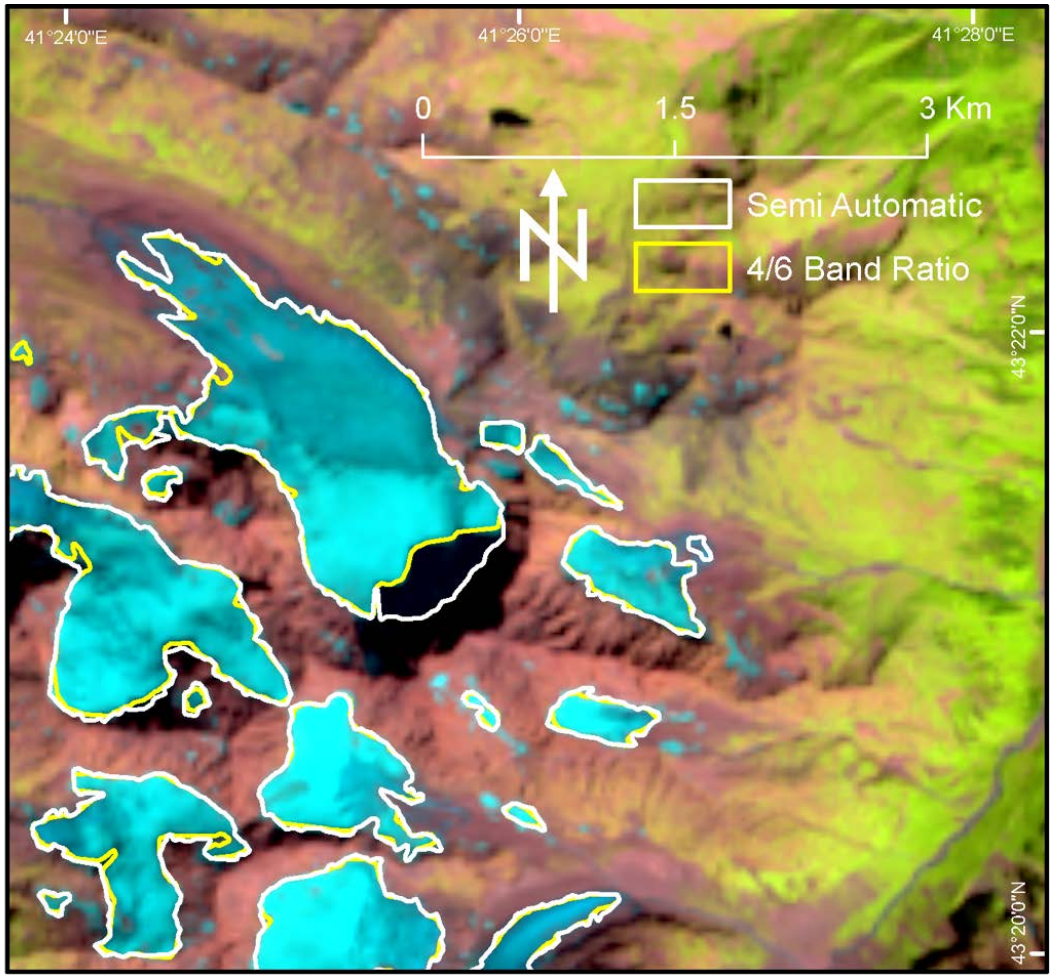
Rpanchromatic/SWIR= DNpanchromatic/DNSWIR



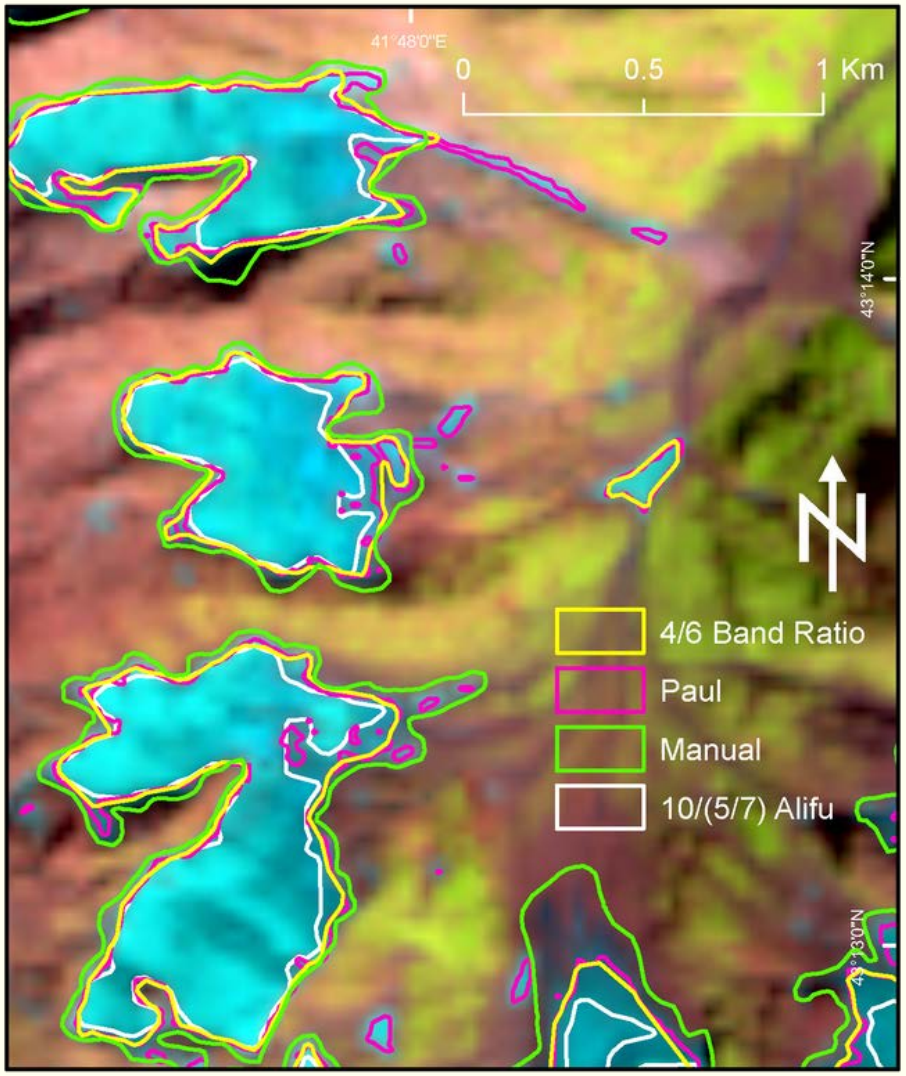


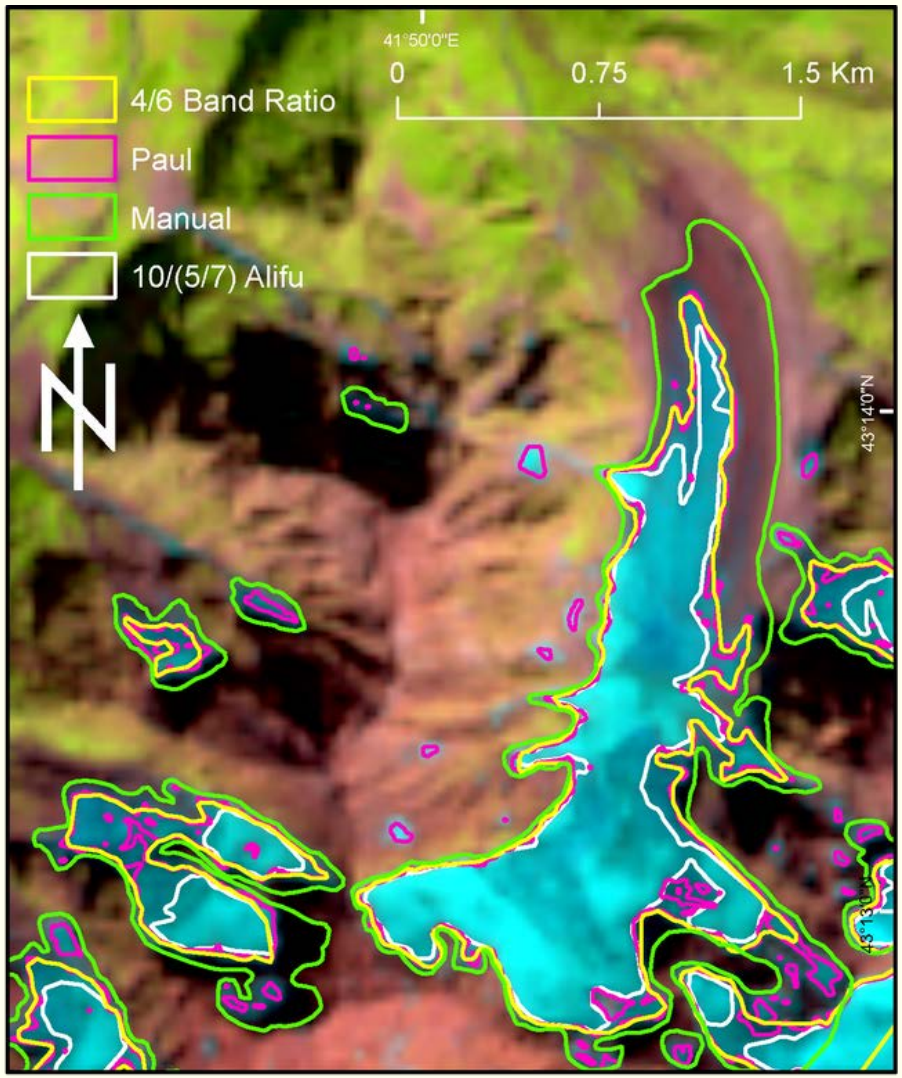
SHADOW/WATER



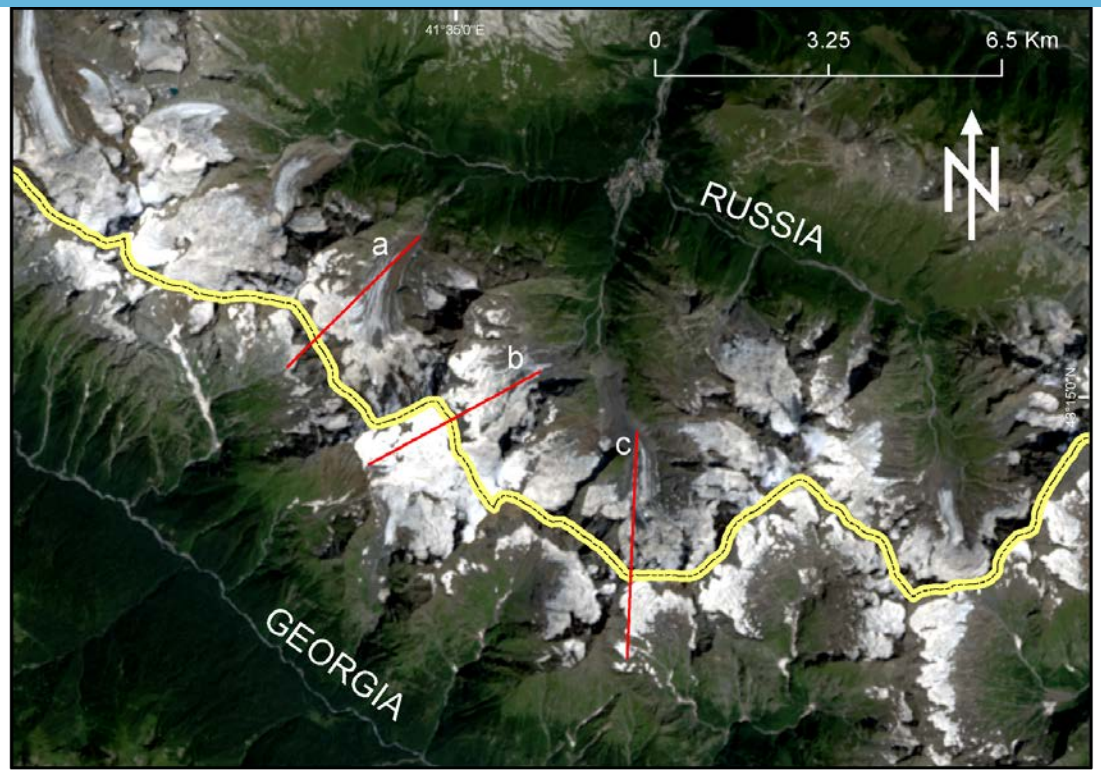


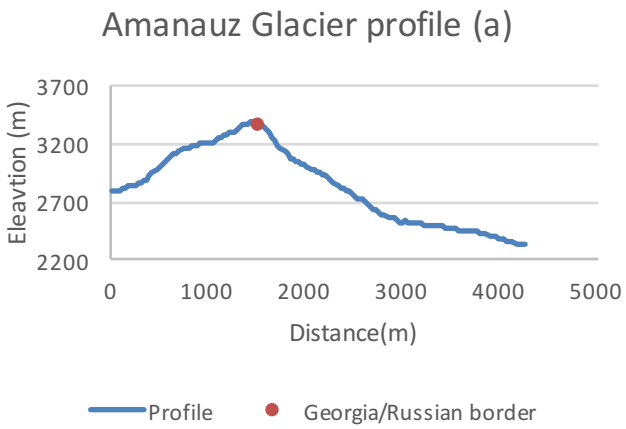
WEST COMPARISON

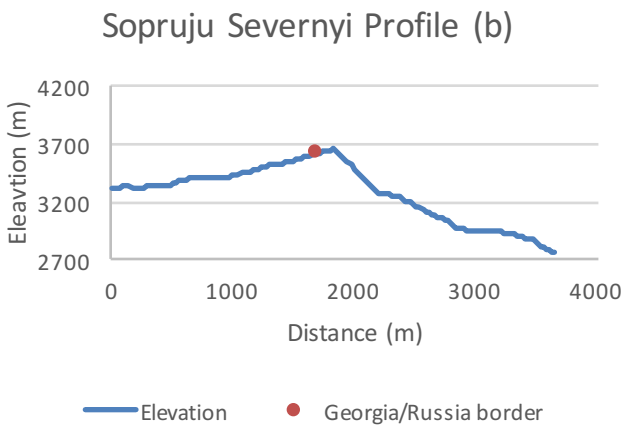


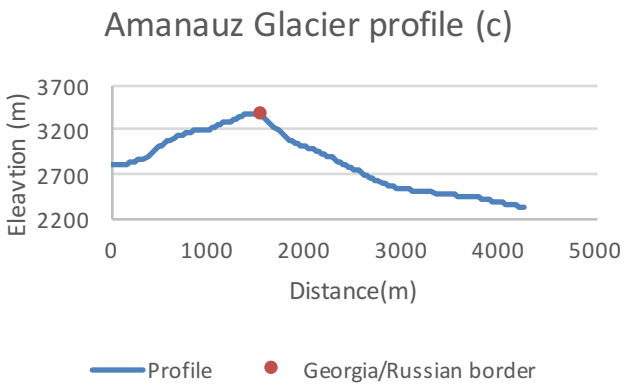


PROFILES

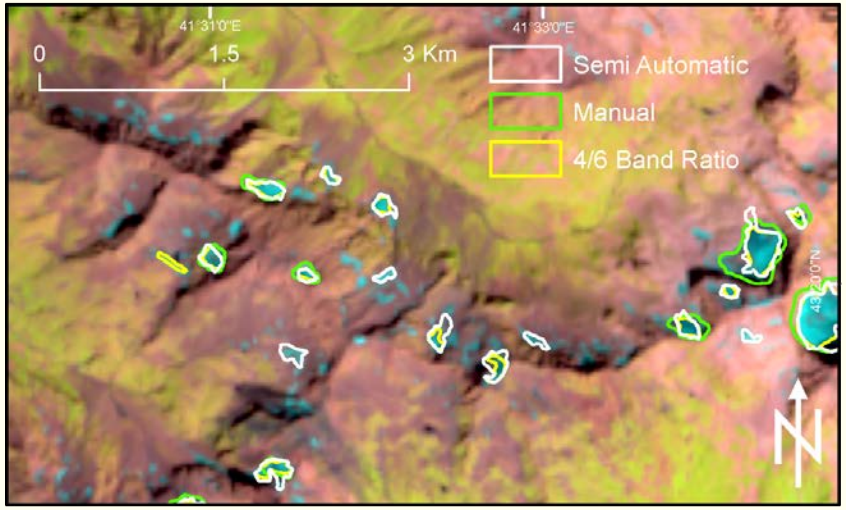

0
3.25
6.5 Km
RUSSIA
GEORGIA
a
b
c

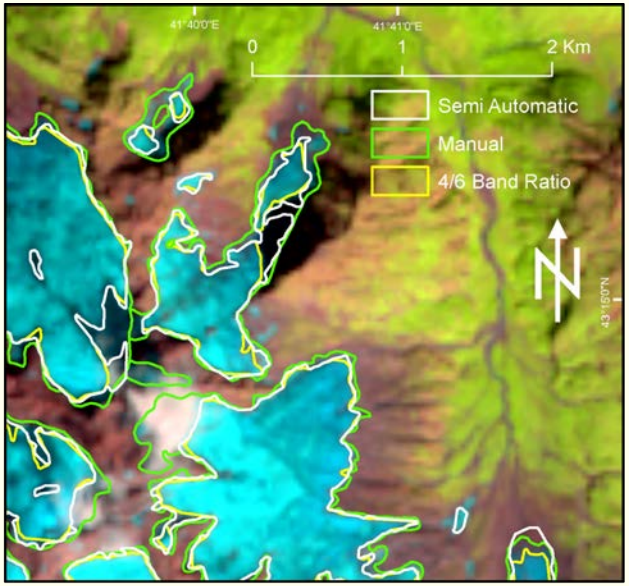

Amanauz Glacier profile (a)
Eleavtion (m)
3700
3200
2700
2200
0
1000
2000
3000
4000
5000
Distance(m)
Profile
Georgia/Russian border

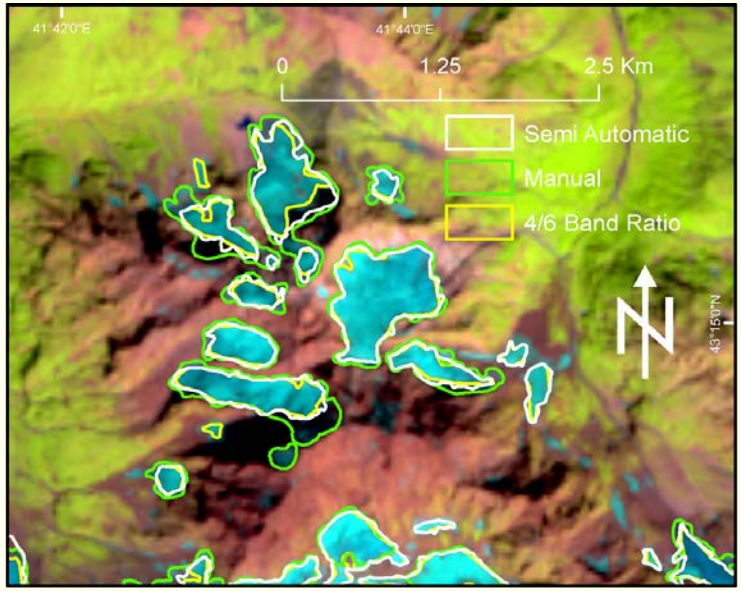

Sopruju Severnyi Profile (b)
Eleavtion (m)
4200
3700
3200
2700
0
1000
2000
3000
4000
Distance (m)
Elevation
Georgia/Russia border

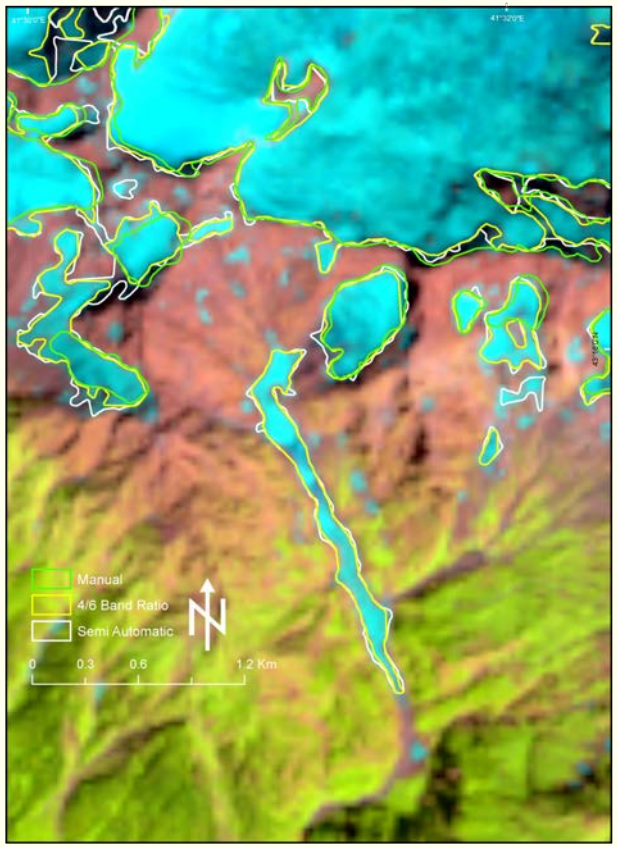

Amanauz Glacier profile (c)
Eleavtion (m)
3700
3200
2700
2200
0
1000
2000
3000
4000
5000
Distance(m)
Profile
Georgia/Russian border

PROBLEMATIC AREAS

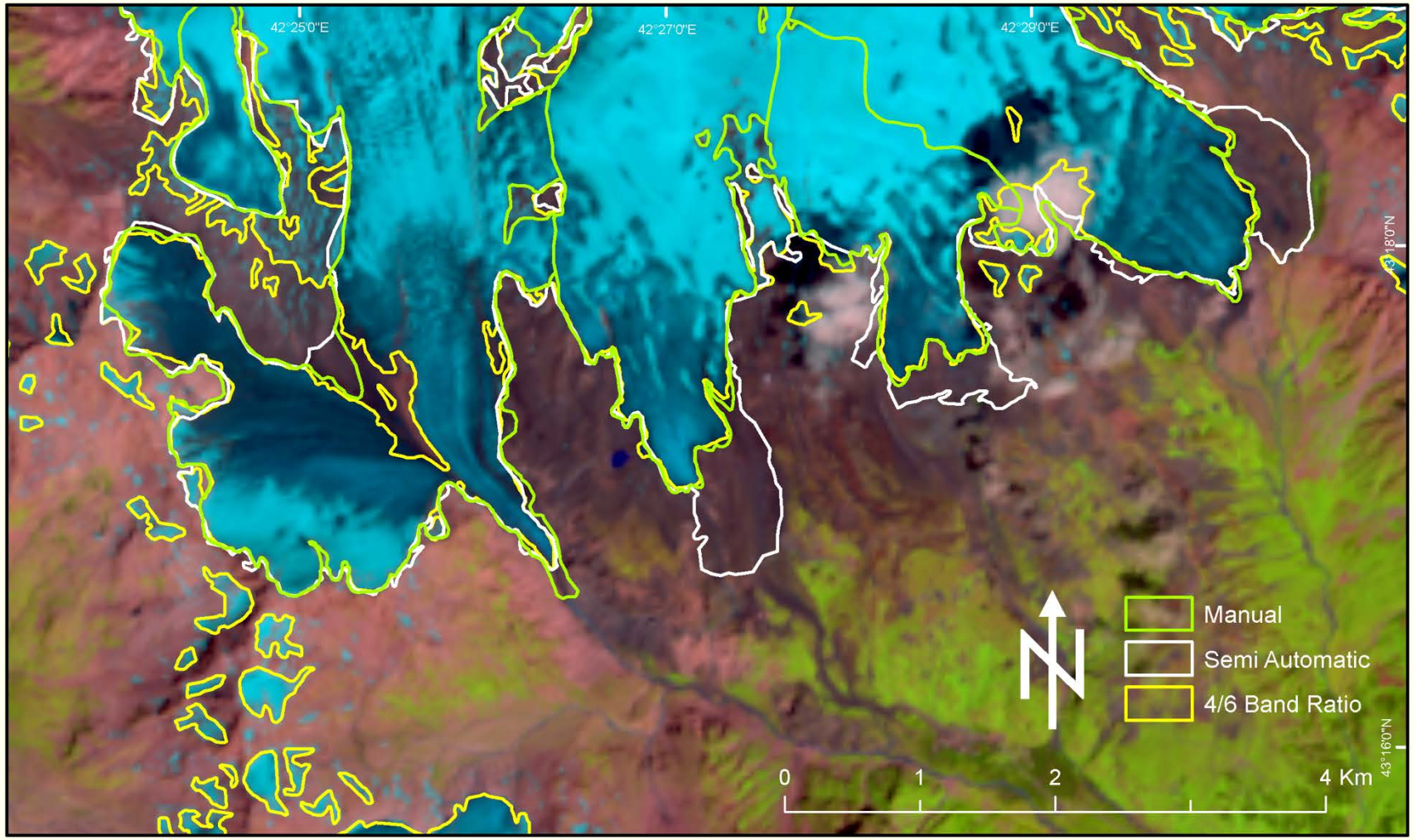




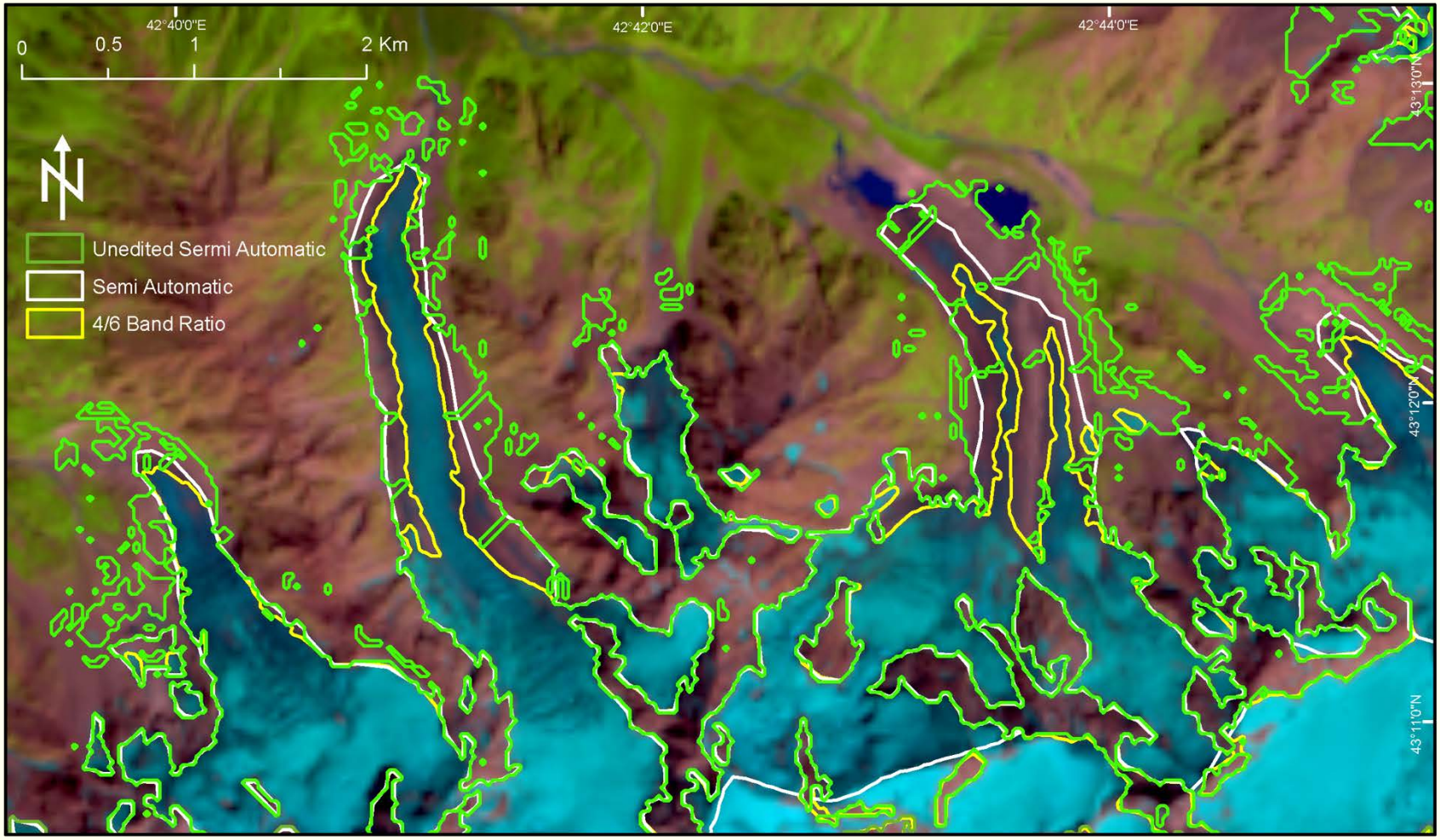




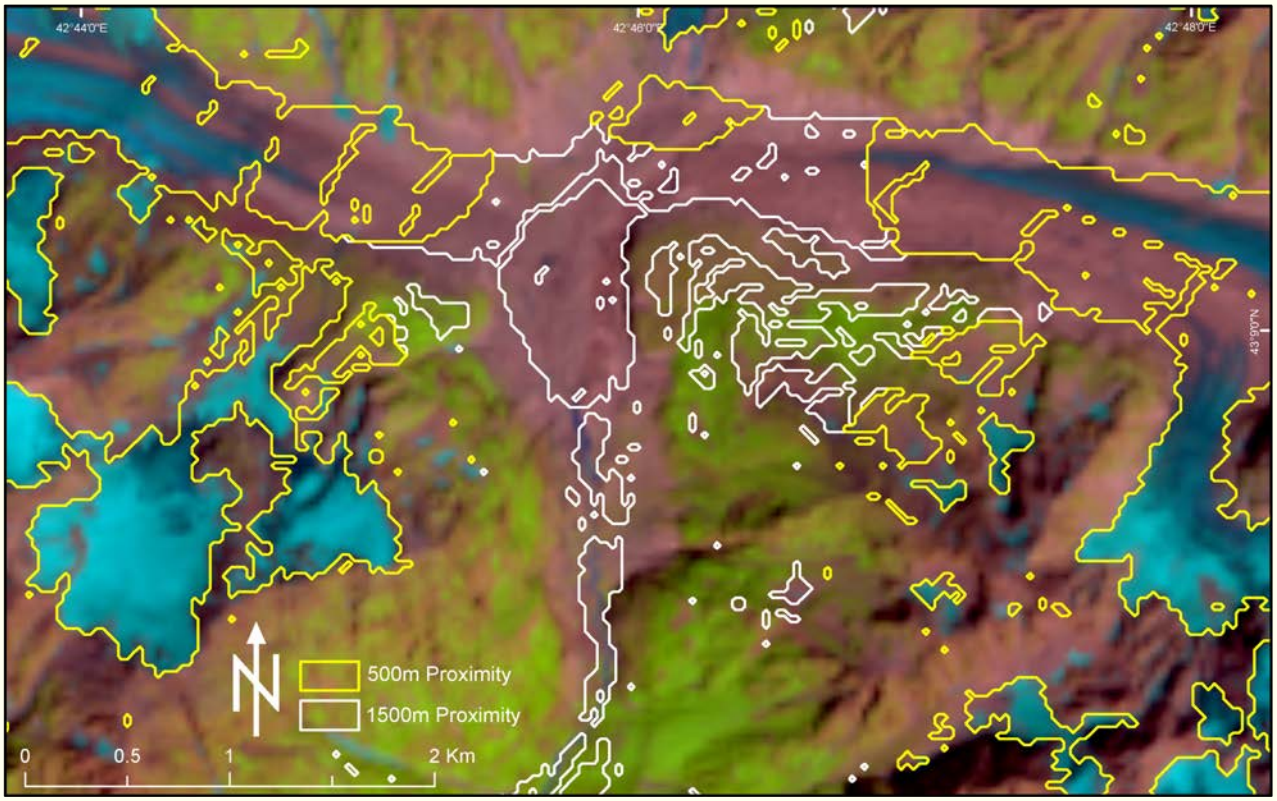
ELBRUS OVERESTIMATION

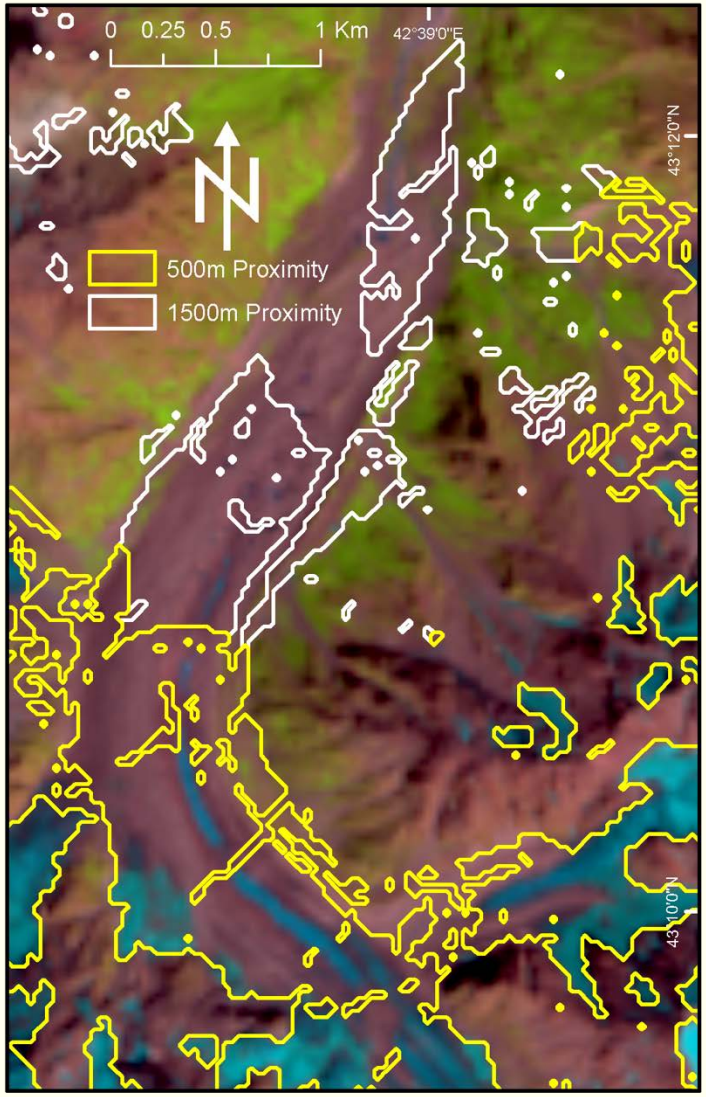


PROXIMITY AND EDITING IMPORTANCE

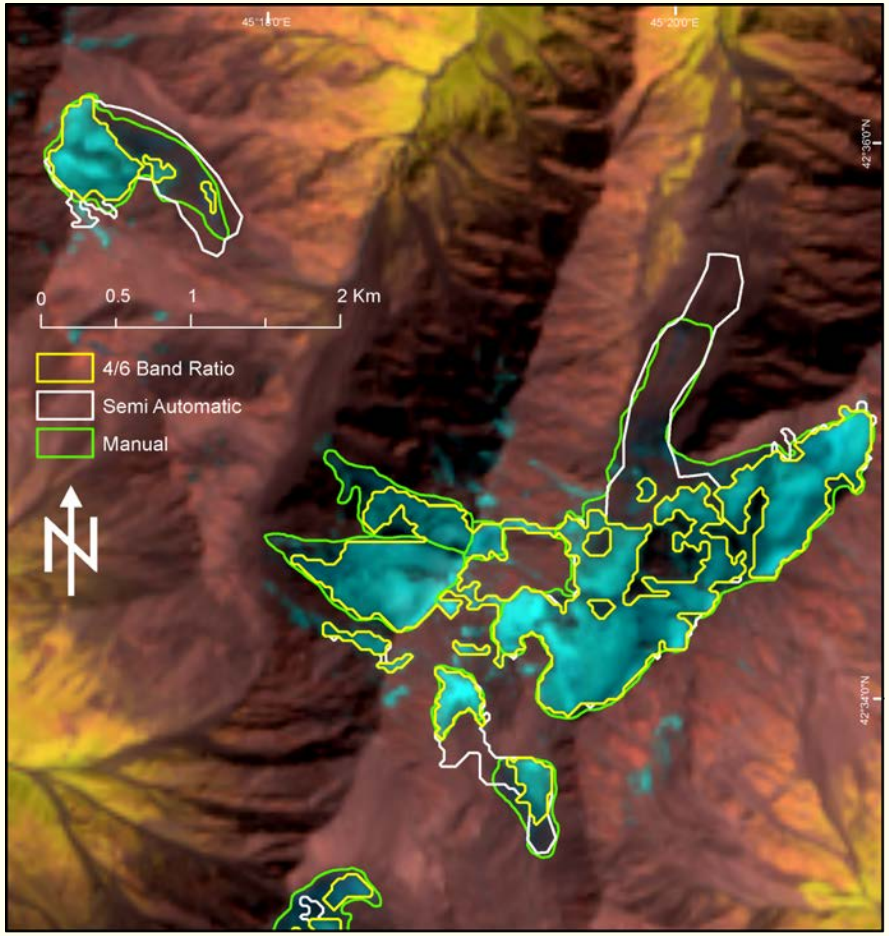


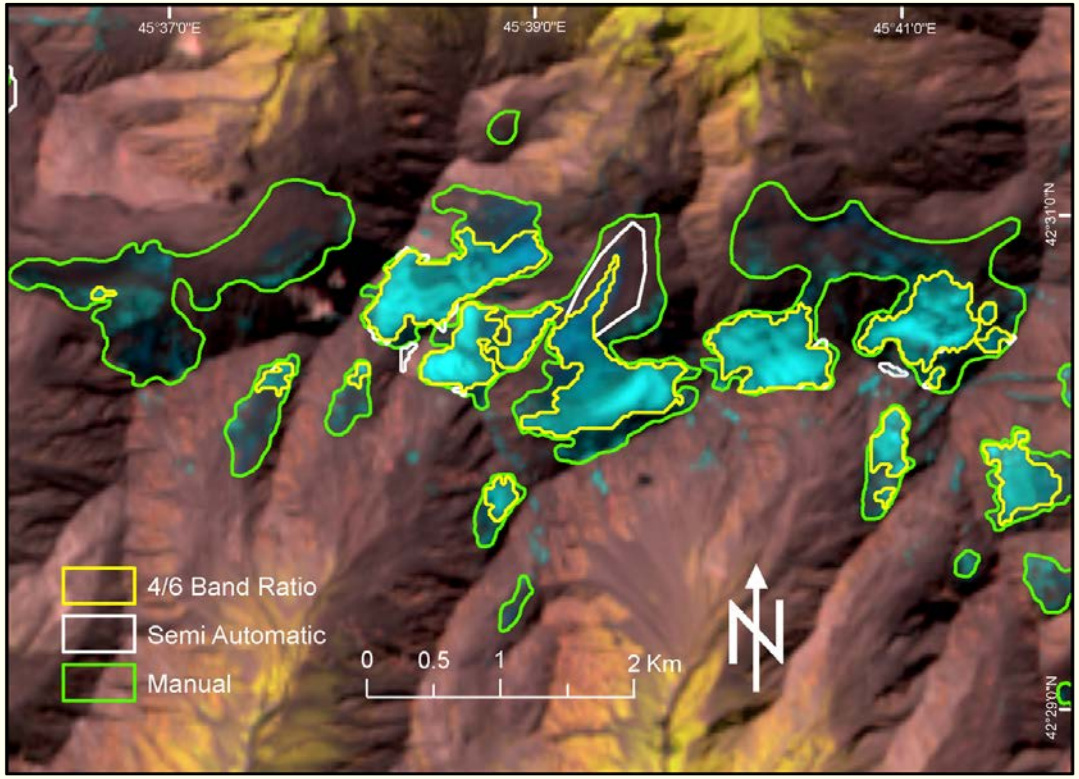
PROXIMITY AND EDITING IMPORTANCE





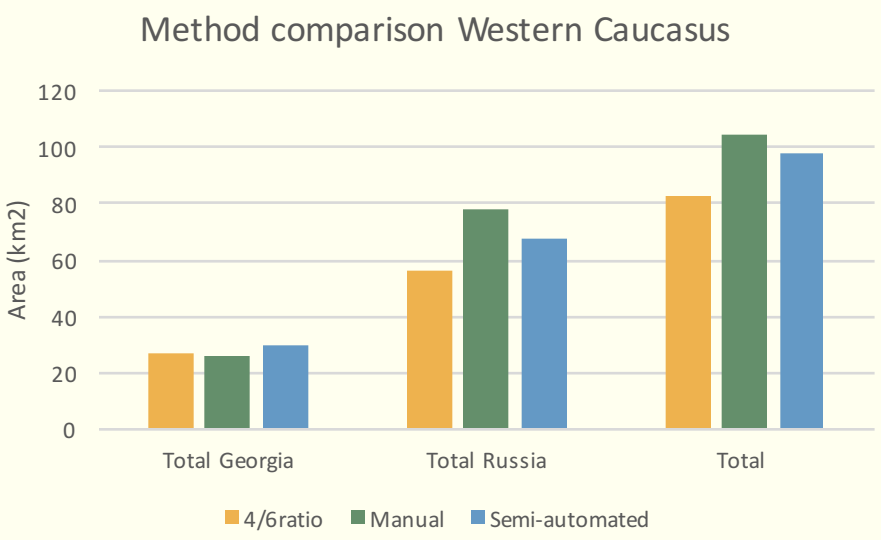
EAST CAUCASUS

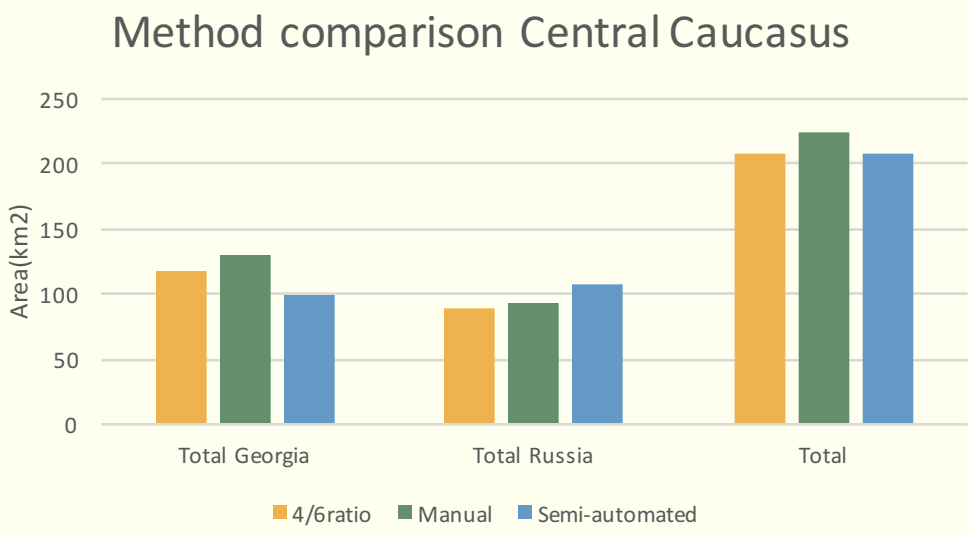


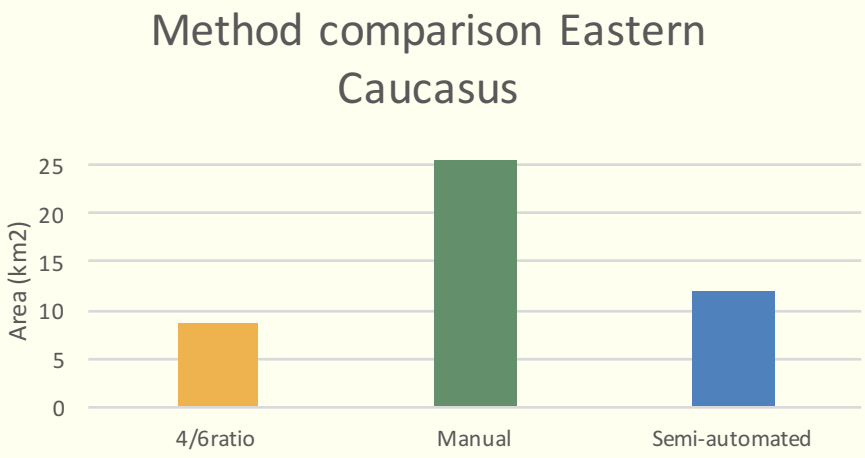


QUALITATIVE RESULTS

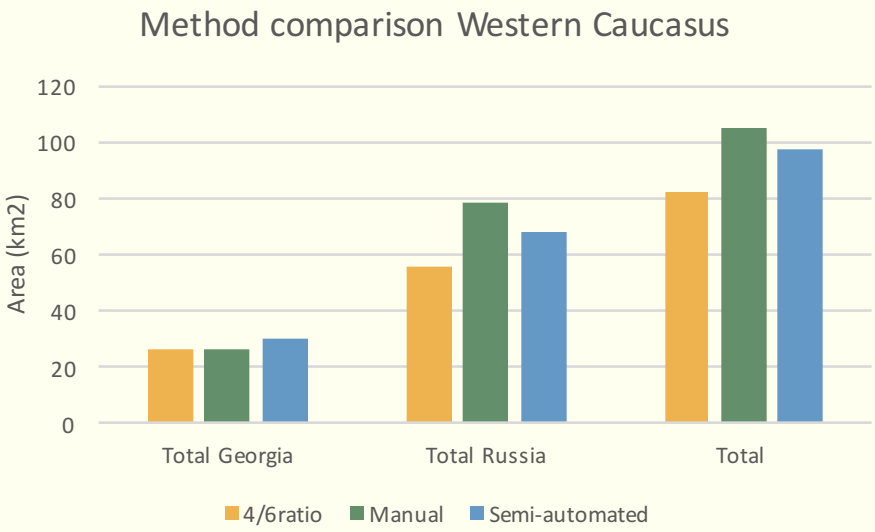
METHOD COMPARISON

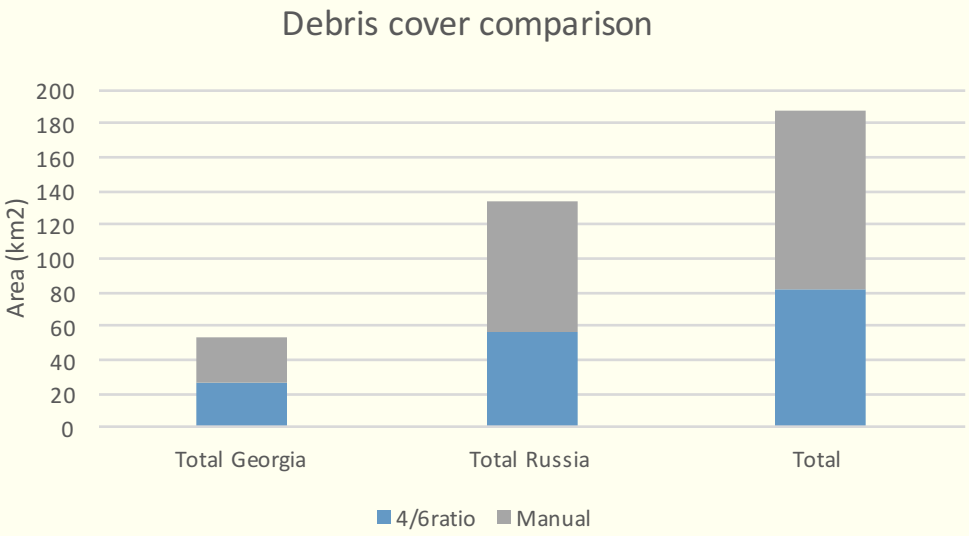






METHOD COMPARISON





Manual – Band-ratio image = Debris covered glacier

ACCURACY

Method	User's Accuracy (%)	Overestimation (%)
4/6 1.8	76.94	2.06
4/6 1.9	69.17	2.76
4/6 2.0	71.68	2.53
4/6 2.1	71.10	2.58
Paul	71.41	2.56
Alifu 10/(5/7)	59.41	3.63
Alifu 11/(5/7)	53.94	4.12
Alifu ((10+11)/2)/(5/7)	54.94	4.03
Semi Automatic	81.48	2.76

ACCURACY

Region	Method	Area (km^2) without buffer	Area (km^2) with 15m buffer	Uncertainty %
West	4/6 Ratio	82.37	92.97	±11.40
	Semi Automatic	97.81	108.56	±9.90
	Manual	104.69	115.25	±9.16
Elbrus	4/6 Ratio	118.61	122.12	±2.93
	Semi Automatic	118.92	121.41	±2.05
	Manual	115.18	118.23	±2.66
Central	4/6 Ratio	208.53	229.64	±9.19
	Semi Automatic	207.37	225.89	±8.20
	Manual	223.71	237.26	±5.71
East	4/6 Ratio	8.69	10.54	±17.55
	Semi Automatic	11.96	15.84	±24.46
	Manual	25.34	28.34	±10.59

CONCLUSIONS

CONCLUSIONS

-The panchromatic band would be better suited to analyzing smaller glaciers,
- The resolution of the thermal band was too coarse to accurately delineate glacier outlines
-semi automatic technique performed well and often identified more glacier area than a 4/6 band ratio alone.
-a large amount of post-processing was needed to and reduce outliers.
- Local knowledge or an understanding of the topography of region is important
-There is no clear 'best option' for glacier delineation and the type of glacier and region should determine which method is used

FUTURE STUDIES

-Integration of field data in order to create more accurate outlines.
-use of different band ratios and the use of different, higher resolution satellite images such as those from Sentinel
-Exploring plan and profile curvature, more complex band ratios or movement dynamics could prove useful in improving the accuracy of
future glacier inventories.

LIMITATIONS

-Sample areas of the Caucasus region are assumed to be representative of the whole area

-A wider variety of methods would also have allowed for a better cross analysis of methods.

-Comparison of outlines by local experts may have made for an interesting comparison