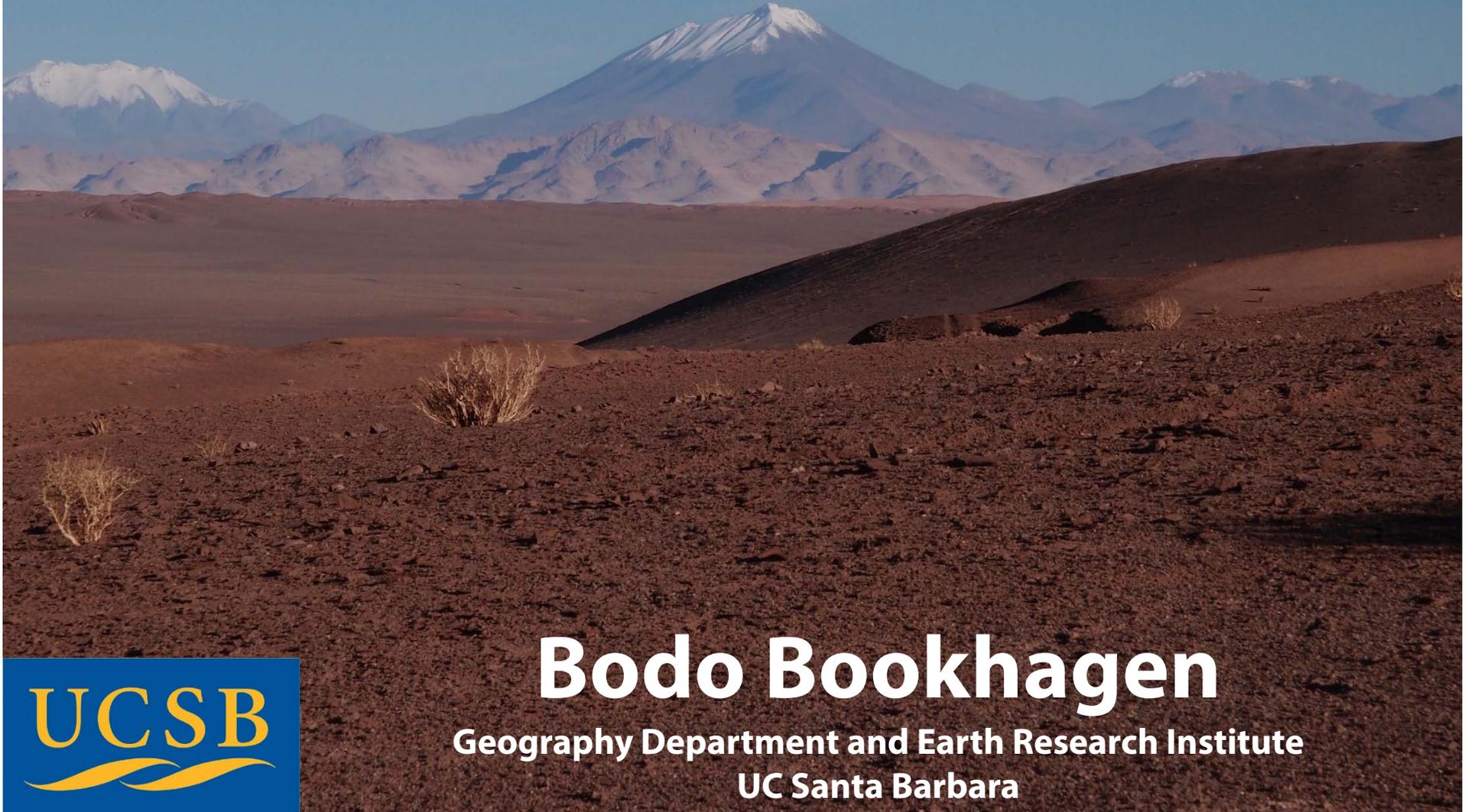# Glacial Retreat Rates in the Central Andes and Mapping of Debris-Covered Glaciers in the Tian Shan
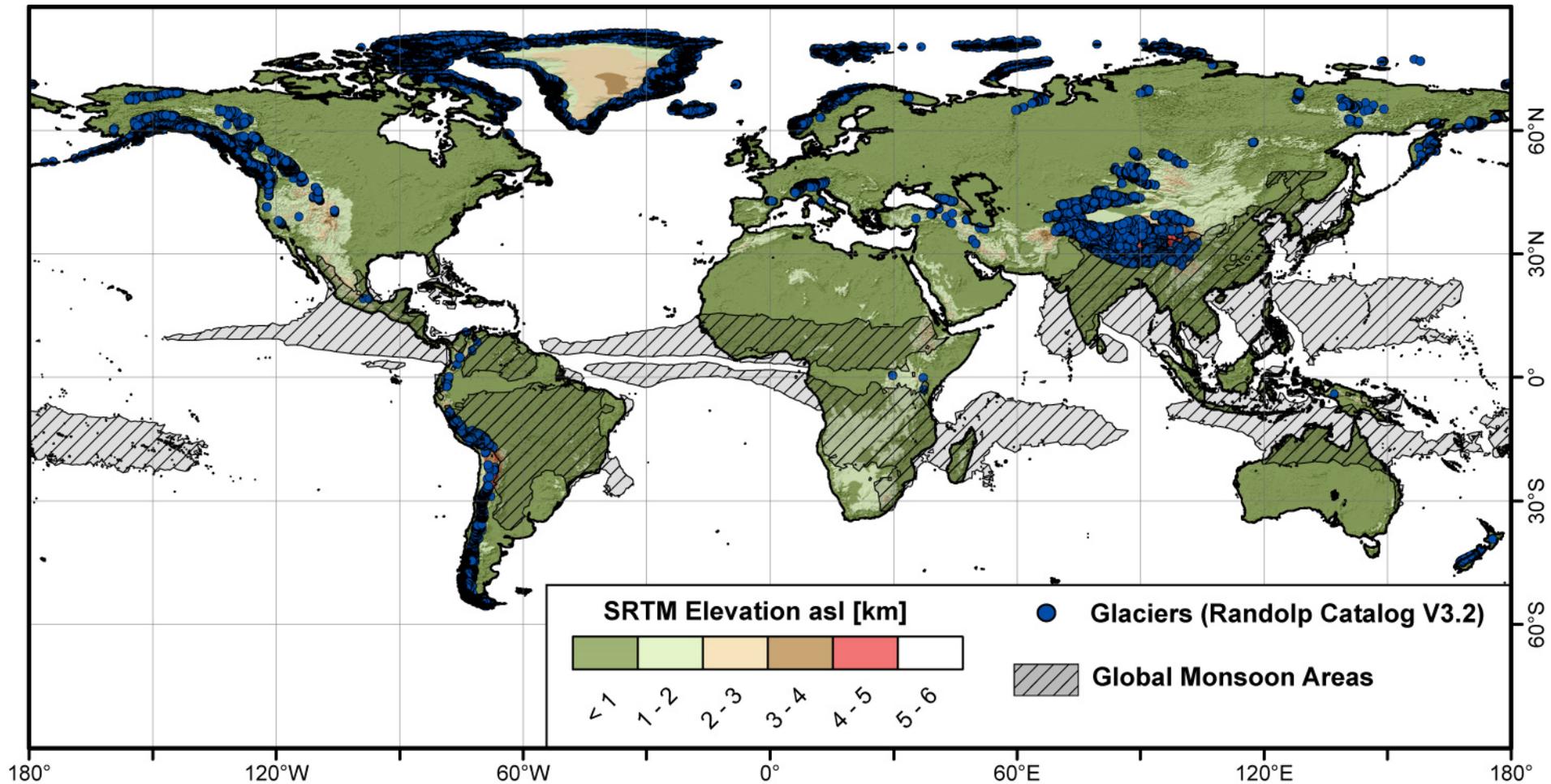
Bodo Bookhagen

Geography Department and Earth Research Institute
**UC Santa Barbara**

UCSB

Global Glacier Distribution and Monsoon Areas

Global distribution of glaciers using the Randolph Catalog (V3.2, blue dots, *Arendt et al., 2012*) and TRMM 3B42V7-based monsoonal areas (gray-hatched areas, *Huffman et al., 2007*).

Global monsoon domains are approximated by: where the grid-cell summer-minus-winter precipitation rate exceeds 2.5 mm/day and the local summer precipitation exceeds 55 % of the annual total.
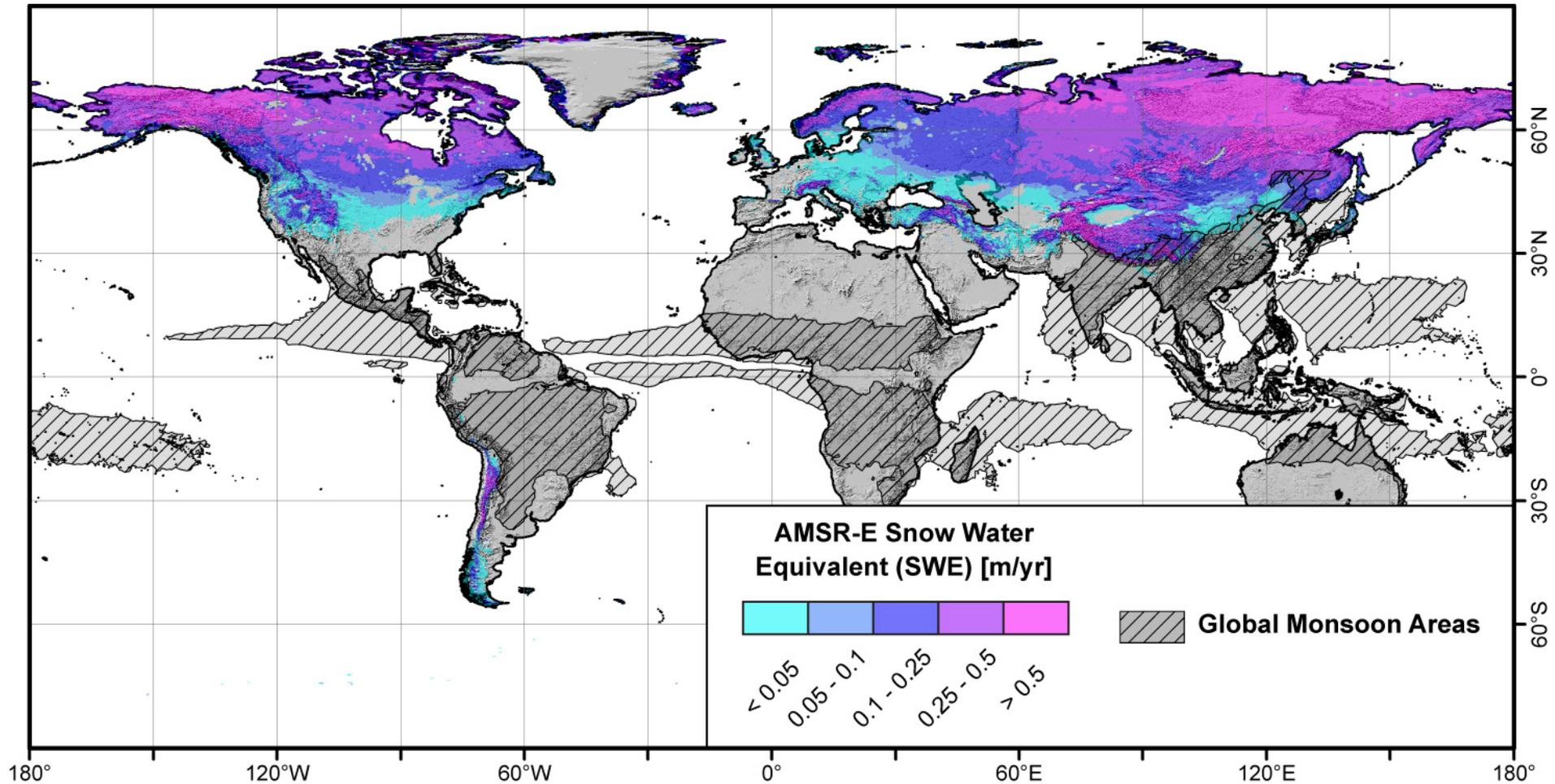
Bookhagen, 2014

Mean Monthly Snowcover
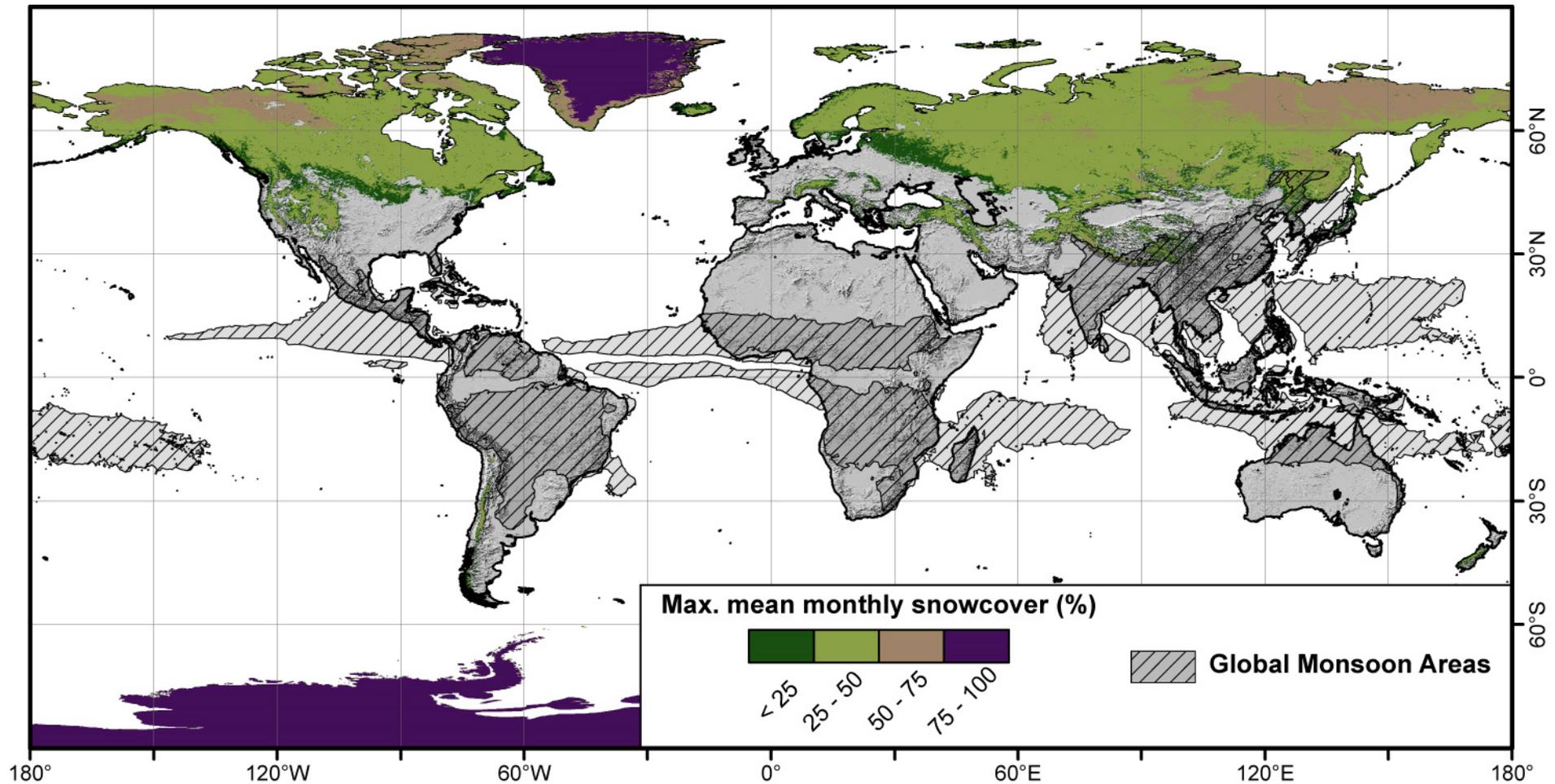
Maximum annual snow cover extent based on MODIS product MOD10C1.005 (*Hall et al., 2006*) from February 2000 to April 2014.
Note the low snow cover for most monsoonal areas, excepting the Himalaya.
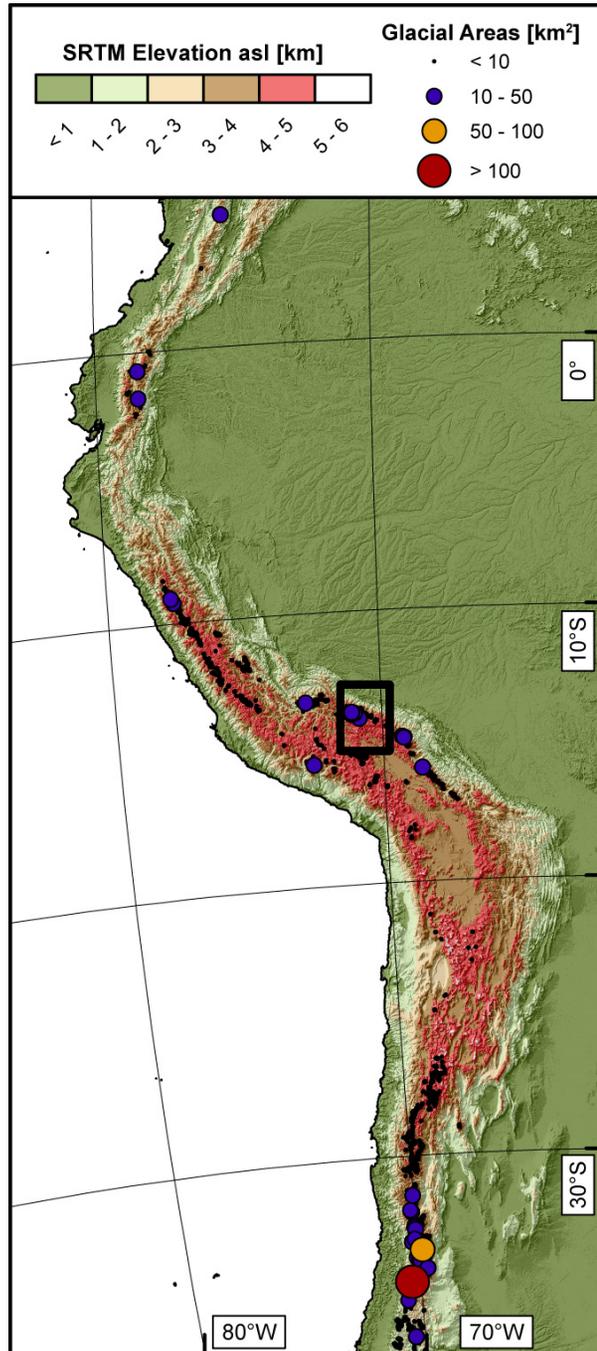
Bookhagen, 2014

Annual Global Snow Water Equivalent (SWE)

Annual snow water equivalent (SWE) based on passive microwave data (AMSR-E) (*Tedesco et al., 2004*) from June 2002 to Oct 2011.
SWE is generally low in monsoon-dominated areas, except in High Mountain Asia.

Bookhagen, 2014

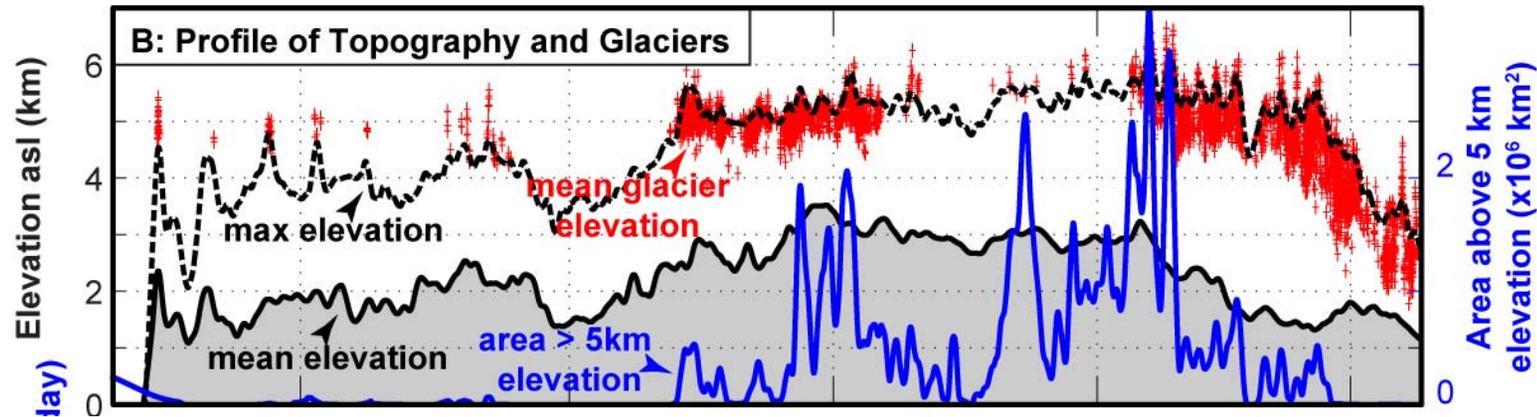# Mapping Glaciers and Snowlines in South America

Mostly small and rapidly retreating glaciers (< 10 km^2)
Low to no debris coverage

Size distribution of glaciers in South America using the Randolph Catalog (V3.2, *Arendt et al., 2012*).

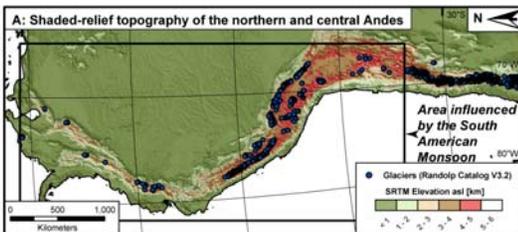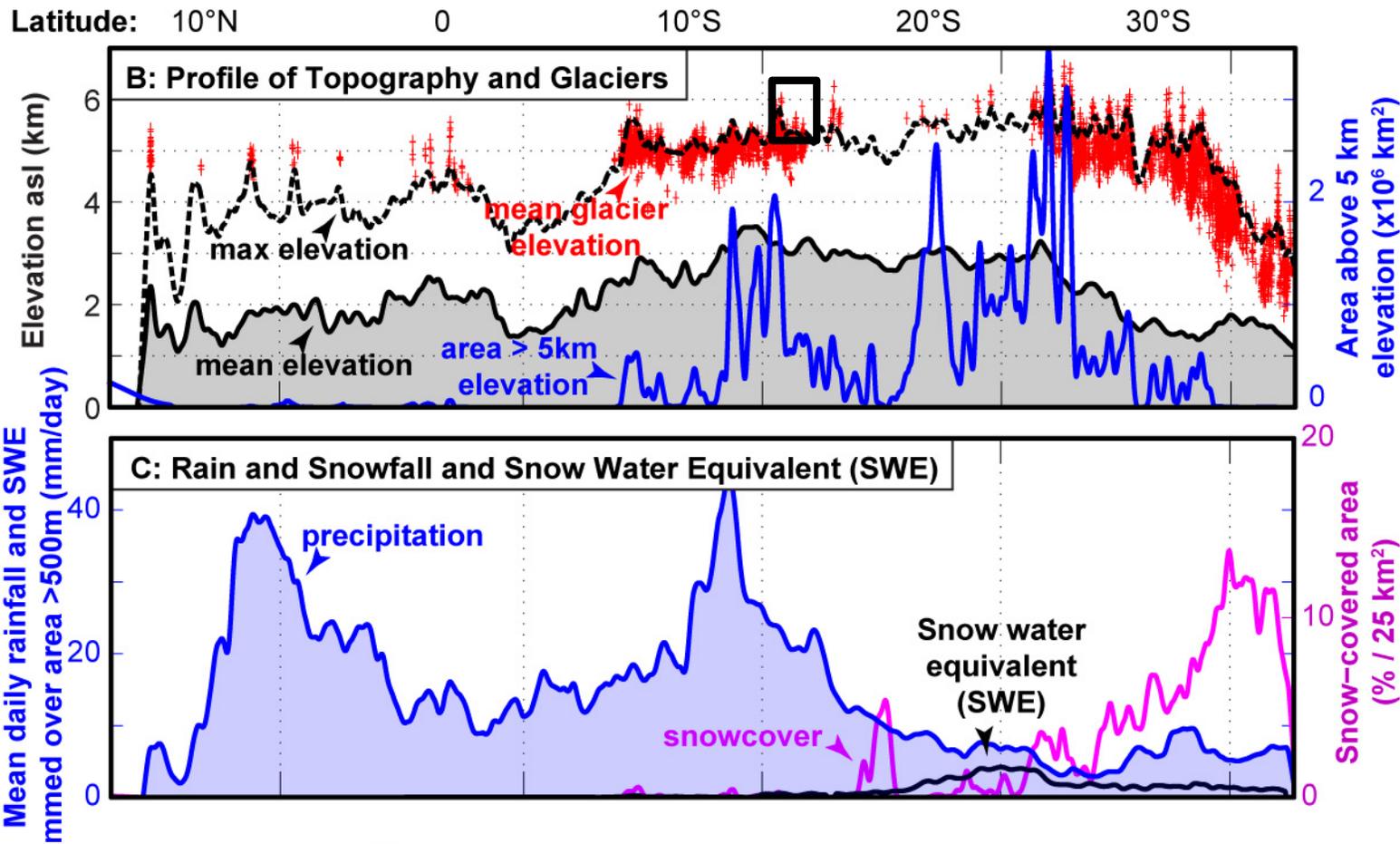*Bookhagen, 2014*

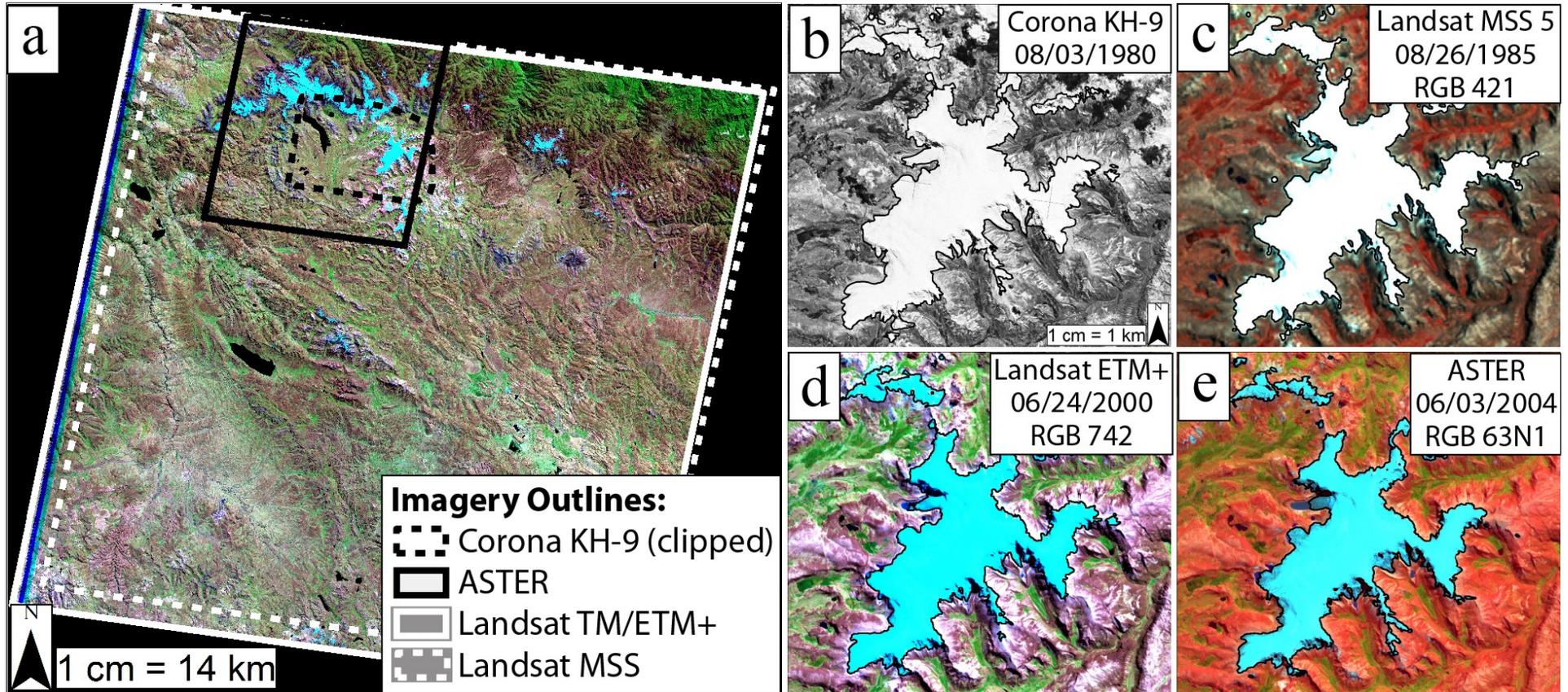# Mapping Glaciers and Snowlines in South America
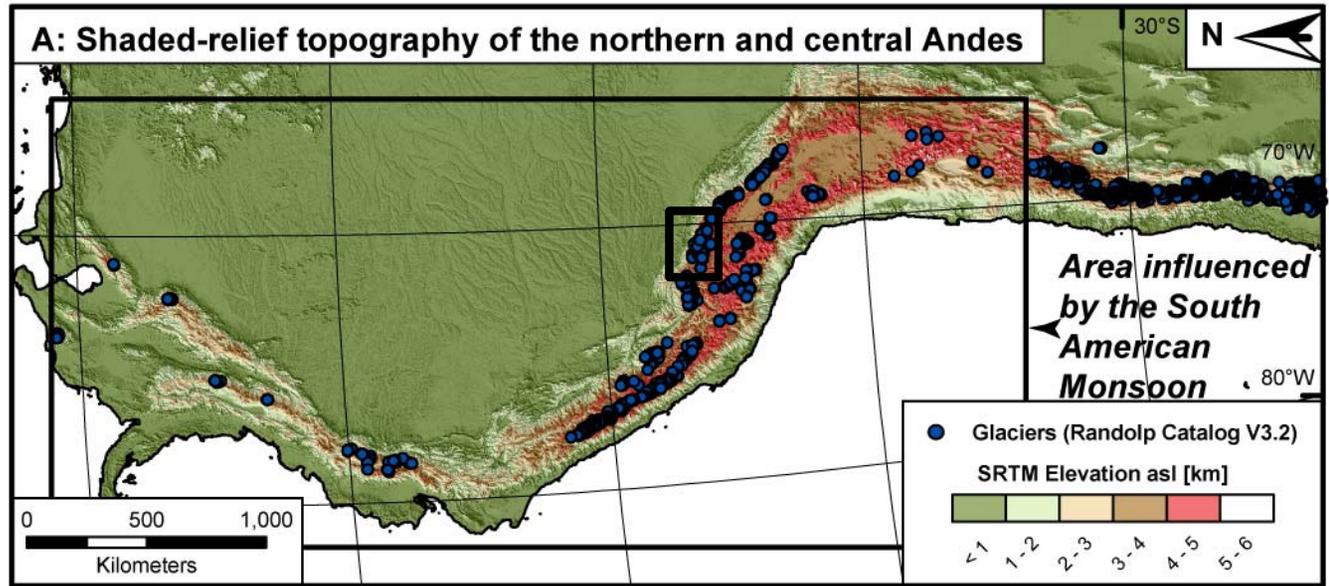
North-to-South profile showing topography and glacial distributions.

Bookhagen, 2014

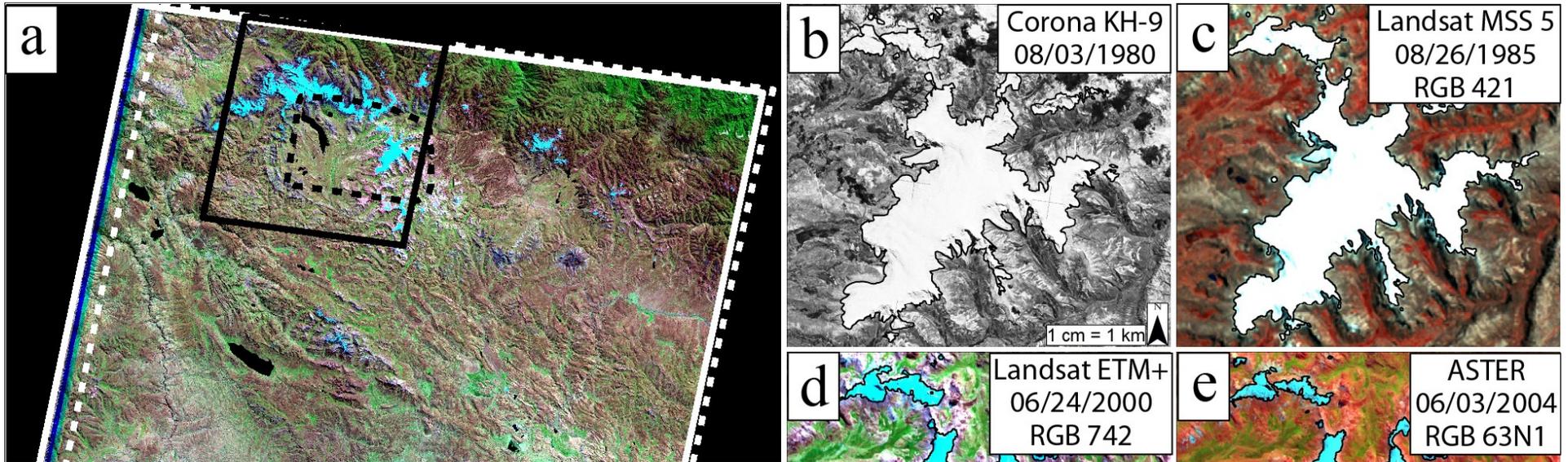# Mapping Glaciers and Snowlines in South America

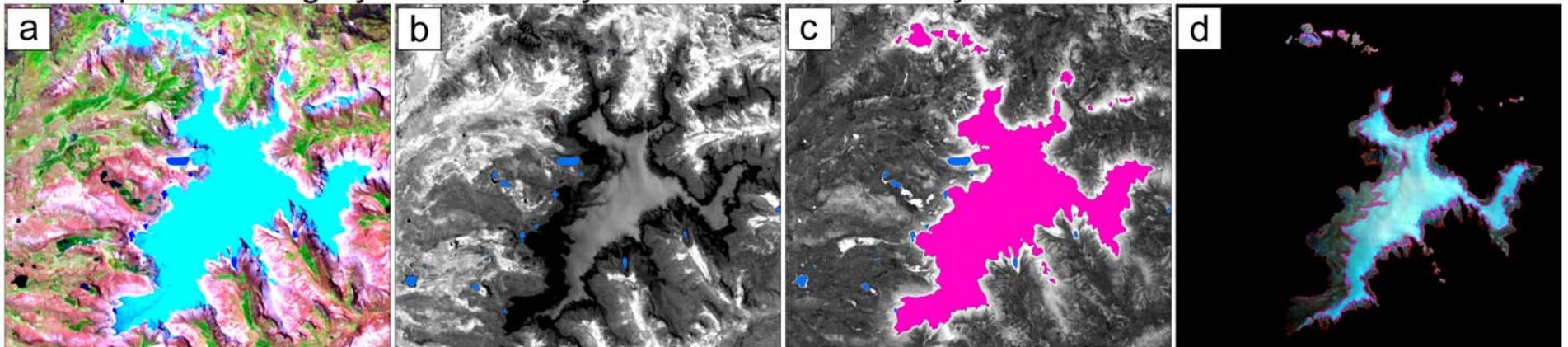North-to-South profile showing topography, glacial distribution, and climatic variables

Bookhagen, 2014

Data used: Declassified CORONA KH-9, Landsat MSS 5, ETM+, ASTER (1975-2011)

Hanshaw and Bookhagen, 2014

Data used: Declassified CORONA KH-9, Landsat MSS 5, ETM+, ASTER (1975-2011)

a

b Corona KH-9 08/03/1980
1 cm = 1 km

c Landsat MSS 5 08/26/1985 RGB 421

d Landsat ETM+ 06/24/2000 RGB 742

e ASTER 06/03/2004 RGB 63N1

Multispectral Imagery → Classify Lakes → Classify Glaciers → Delineate Snowline

a
b
c
d

Hanshaw and Bookhagen, 2014

Glacial Retreat Rates for the Quelccaya Ice Cap

Glacial Area for the Quelccaya Ice Cap (Glacial ID: 1)

Legend:
- × Landsat TM/ETM+: B3/B5 & B1
- □ Corona and ASTER (w/o SWIR): Hand
- ○ Minimum area for each year

Annotations on plot:
- 08/03/80 Corona (63.1 km^2)
- −31%
- 09/16/10 TM (43.7 km^2)

Regression using minimum areas:
Glacial area = X * -0.001559 + 1190
r^2 = 0.93, n = 14, RMSE = 1.44 km^2
Annual decline rate = 0.57 ± 0.10 km^2/yr

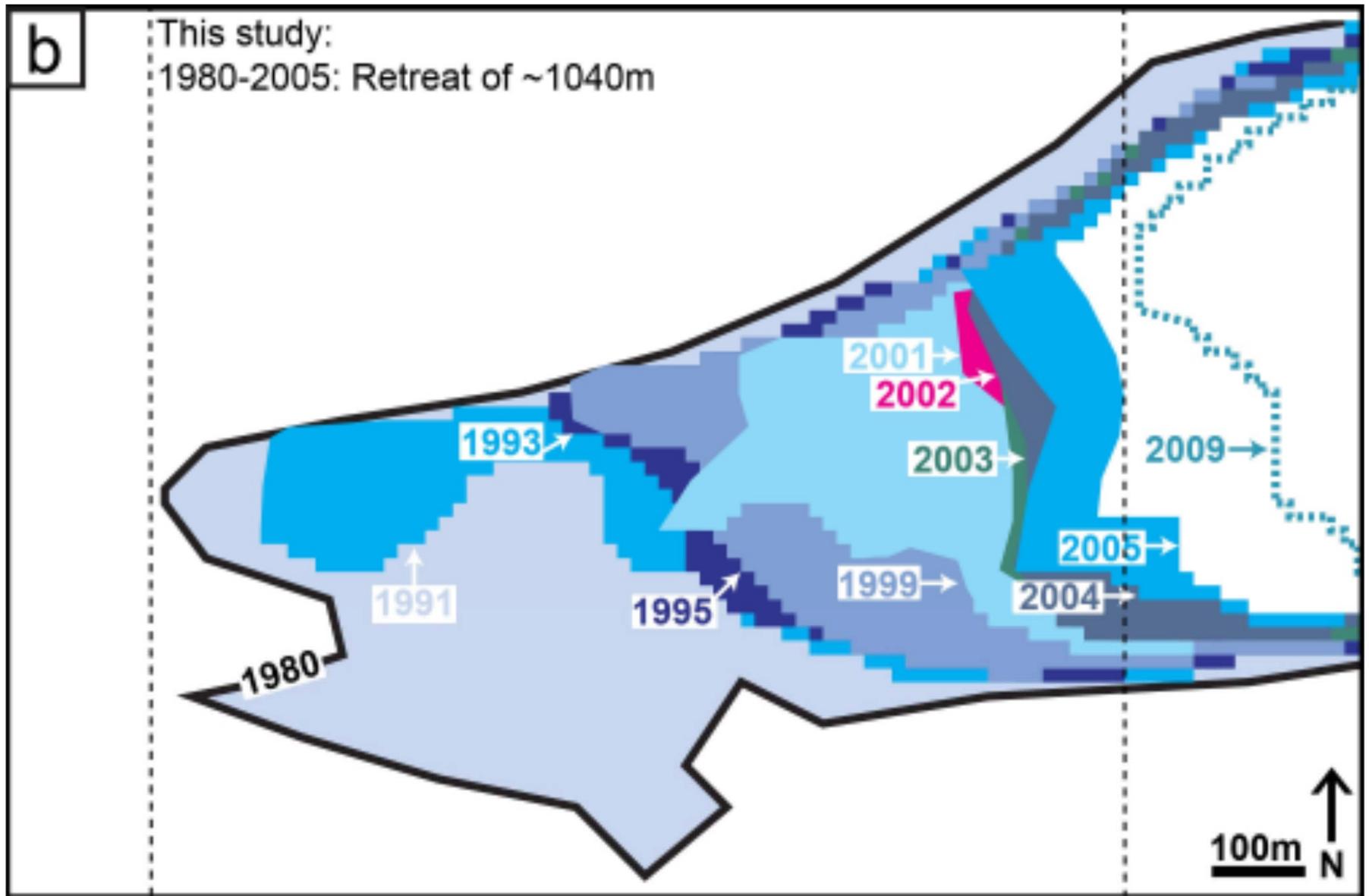Axis labels: Glacial Area (km^2) vs Year

Hanshaw and Bookhagen, 2014

Glacial retreat and lake growth

Lake Area for Lake ID: 8 (a proglacial lake beneath Nevado Ausangate, Glacial ID: 3)

Hanshaw and Bookhagen, 2014
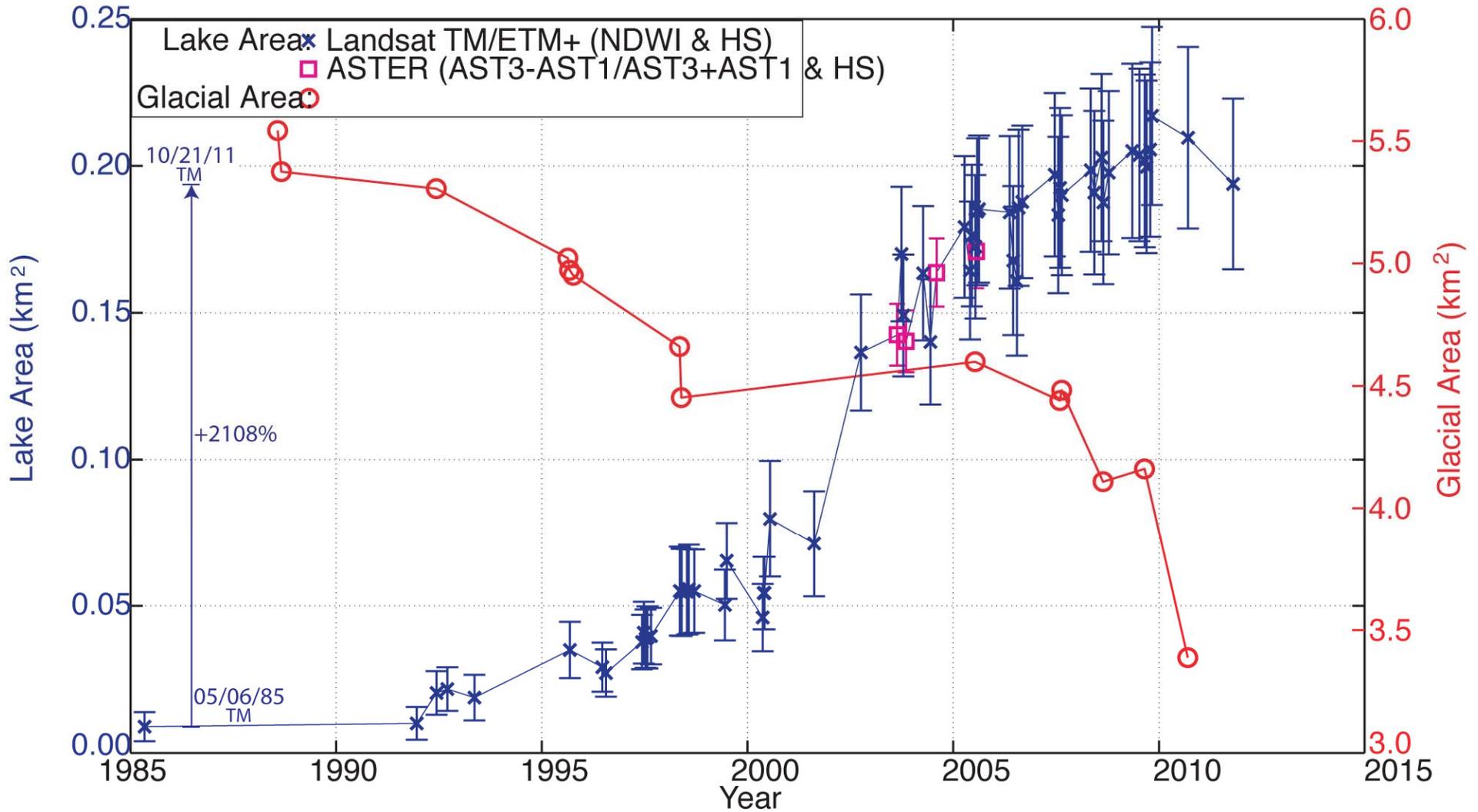
Glacial retreat in space and time

b

This study:
1980-2005: Retreat of ~1040m

1980
1991
1993
1995
1999
2001→
2002
2003
2004→
2005→
2009→

100m N

Hanshaw and Bookhagen, 2014
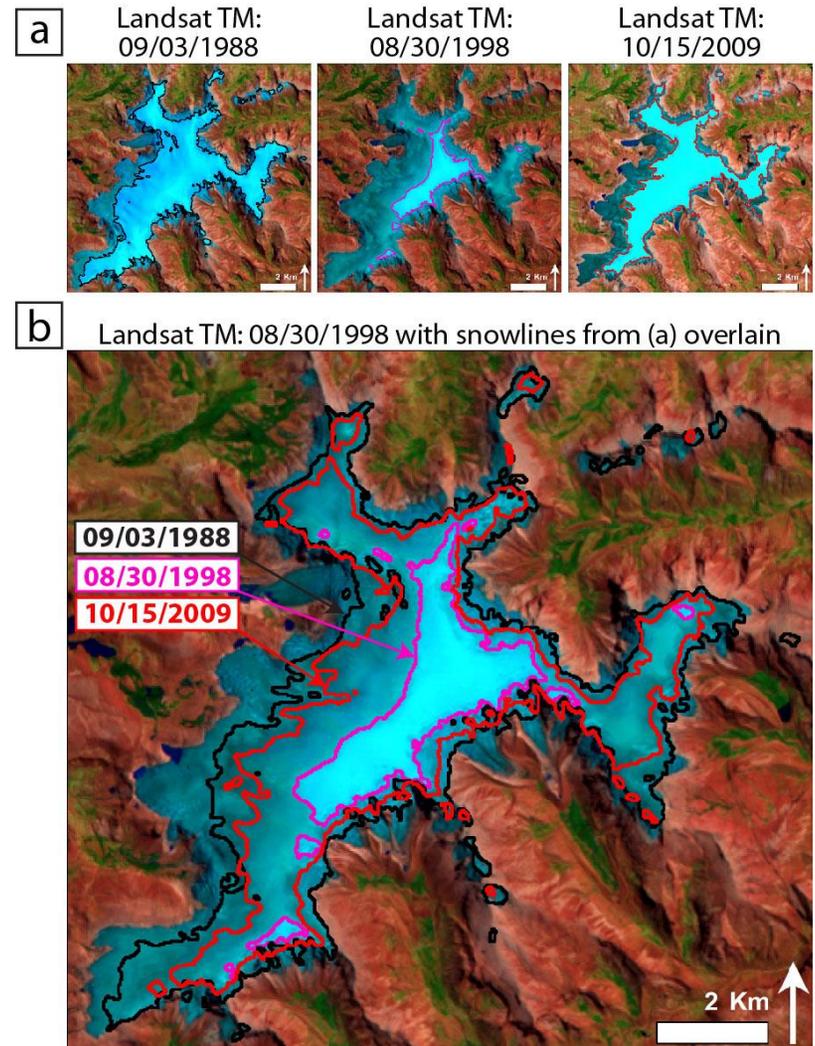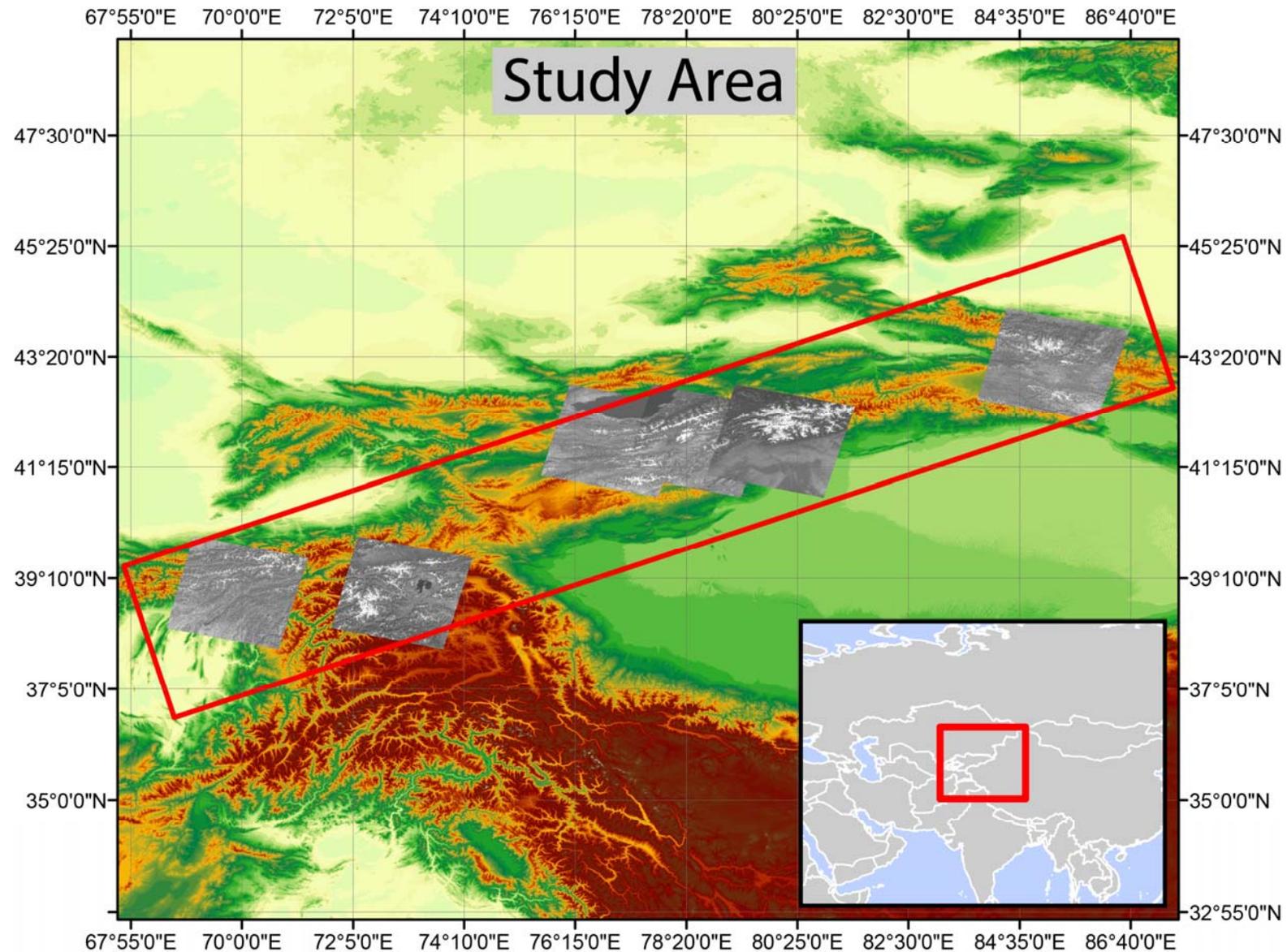
Snowlines and Multispectral Endmember Analysis
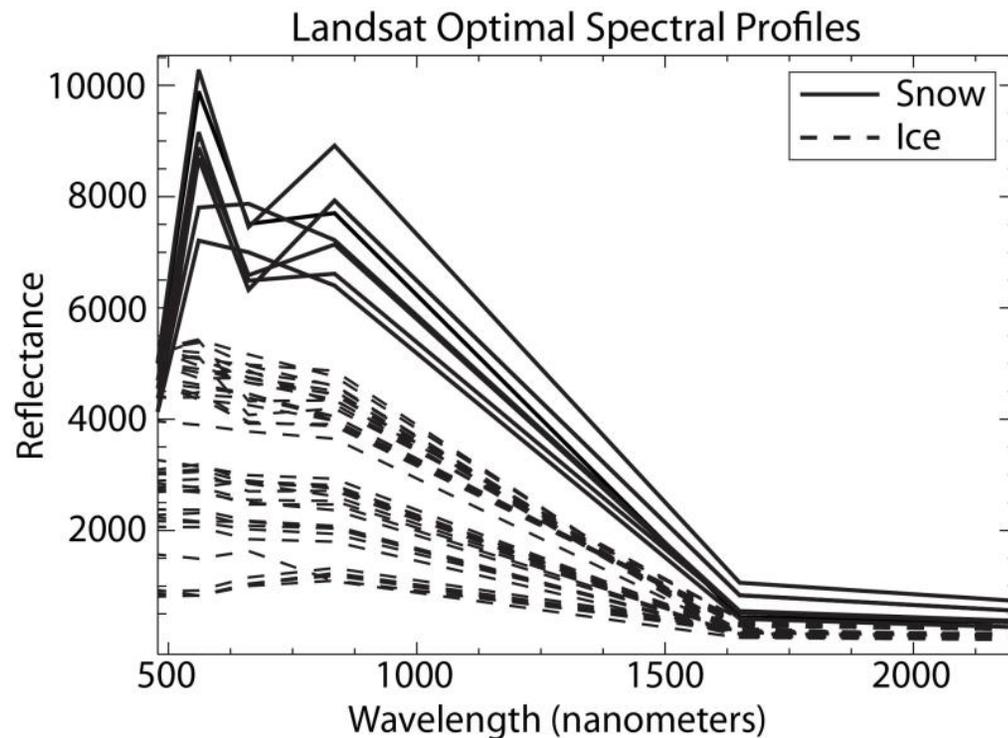
After delineating snow and ice regions, we perform a multiple endmember spectral mixture analysis (MESMA) (*Klein and Isacks, 1999; Roberts et al., 1998*).
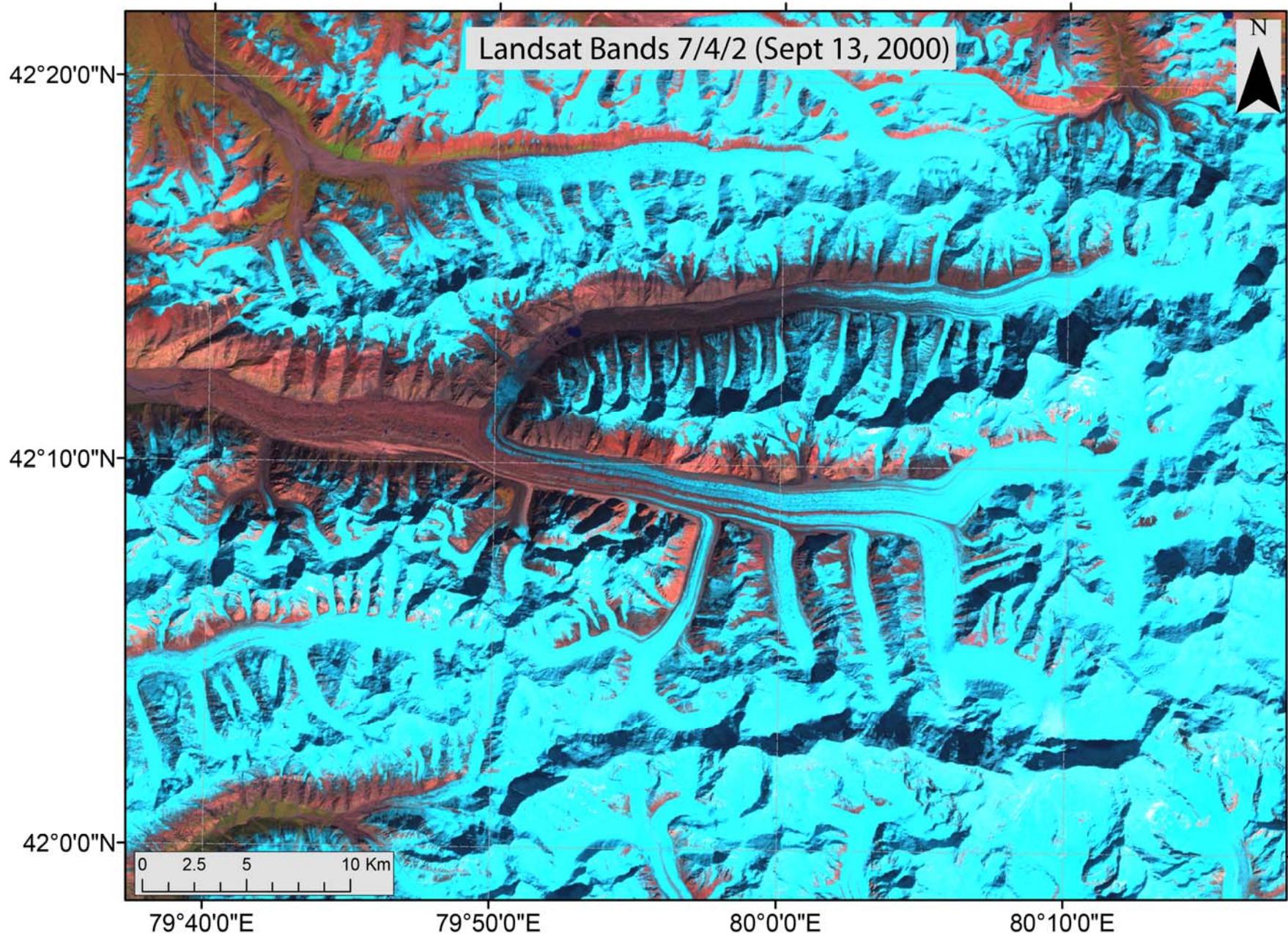
Hanshaw and Bookhagen, 2014

Glacial Retreat of Debris-Covered Glaciers in the Tien Shan

Smith and Bookhagen, in preparation

Delineation of Debris-Covered Glaciers

Landsat Bands 7/4/2 (Sept 13, 2000)

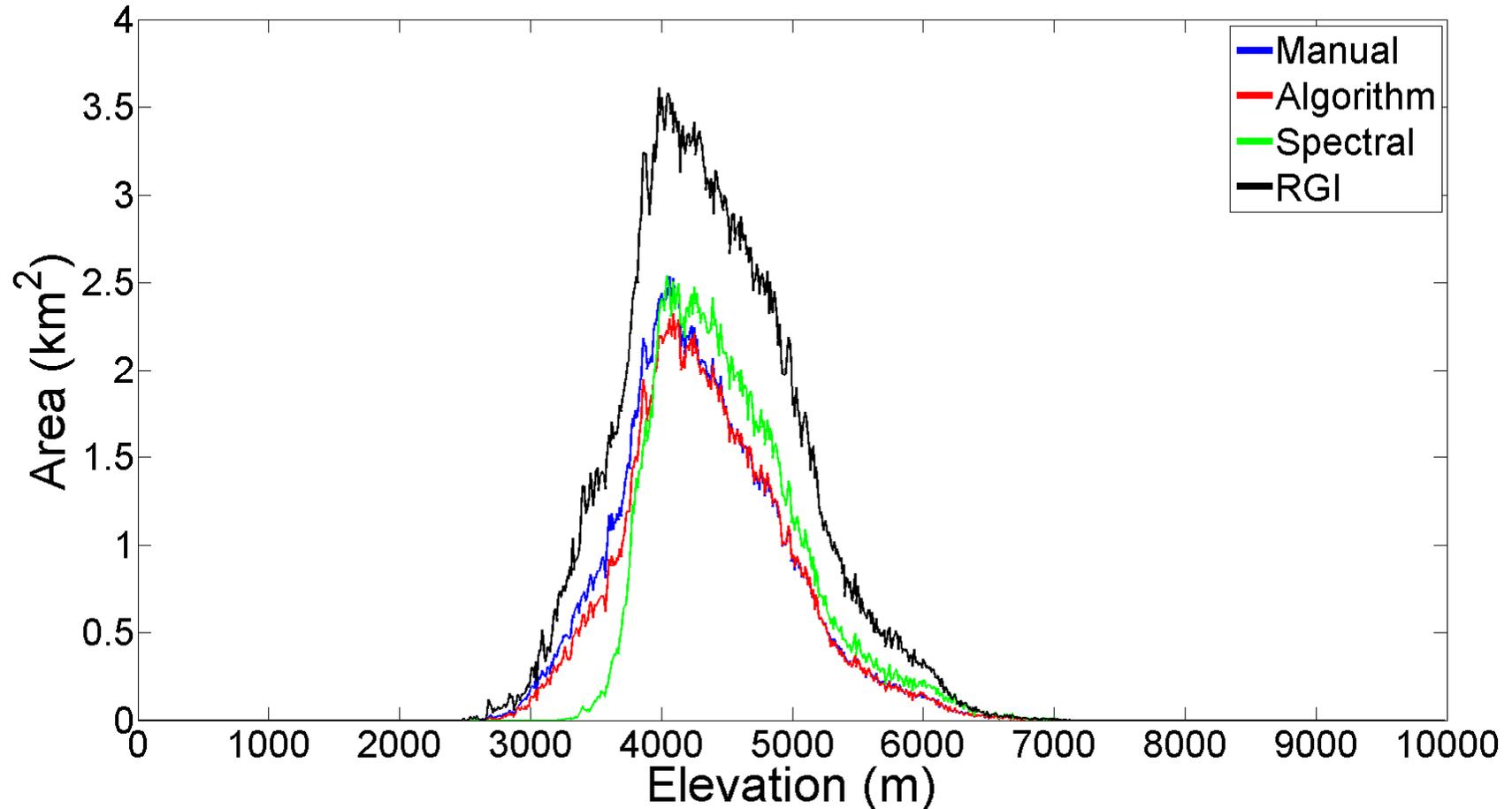*Smith and Bookhagen, in preparation*

Legend

Manual Glacial Outlines

Satellite-Ratio Only Classification

Automatic Glacial Outlines

LE71470312000257SGS00

Landsat Band 7

Landsat Band 4

Landsat Band 2
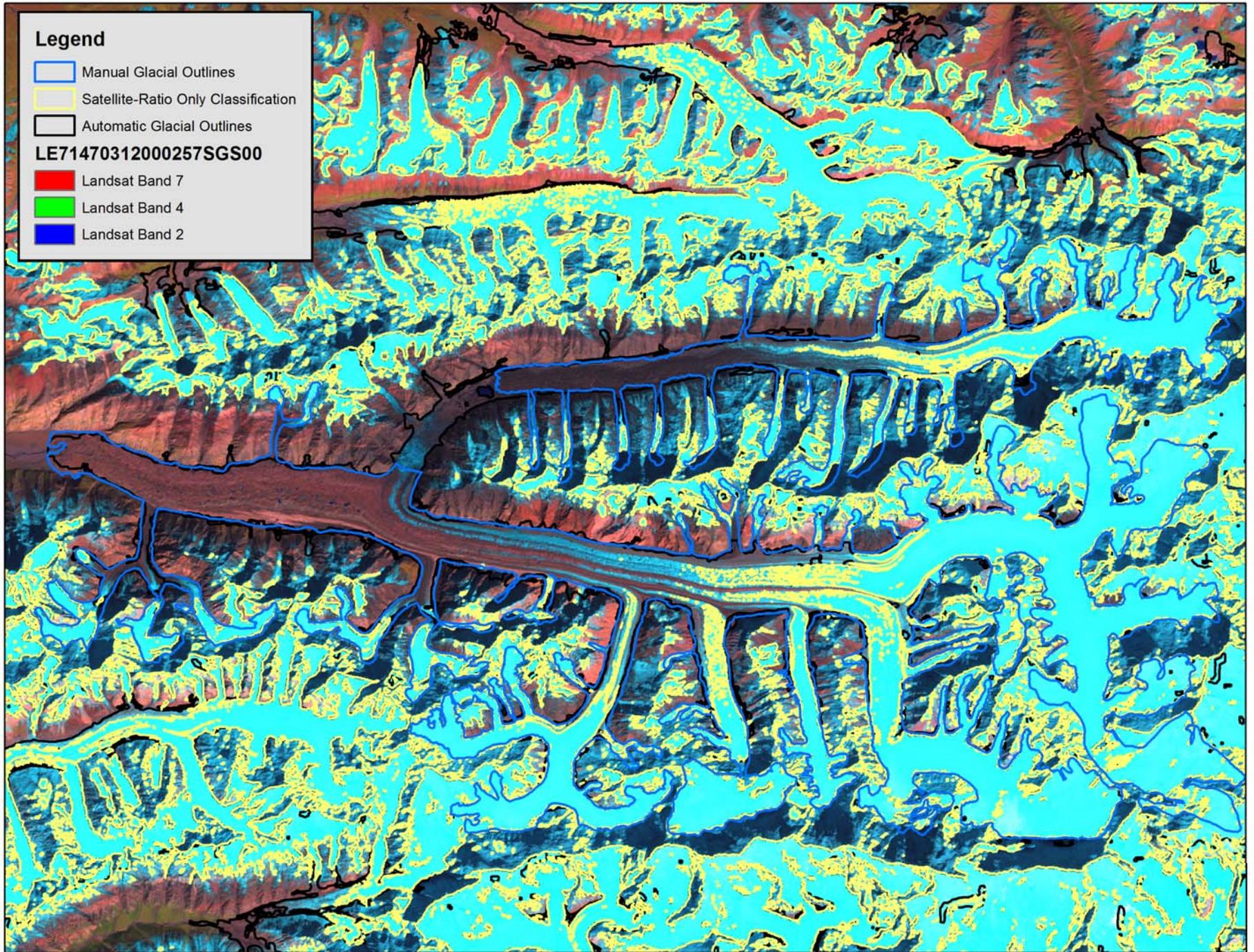
Validation of Glacial Mapping in the Tian Shan

Two control datasets based on manual delineation of ~700 (~380 km^2) glaciers each (1998, 2010) in the Tien Shan are used for validation.

Areal Differences for two Control Datasets for the Tian Shan

Smith and Bookhagen, in preparation