Changing Glaciers and Hydrology in Asia

"The science of climate change and glacier melt/retreat, and the projected impacts on water resources in the region."

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Funding for the research summarized here was provided by:
World Bank, USAID, NASA

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The Glaciers of the Hindu Kush-Himalayan Region

A summary of the science regarding glacier melt/retreat in the Himalayan, Hindu Kush, Karakoram, Pamir, and Tien Shan mountain ranges

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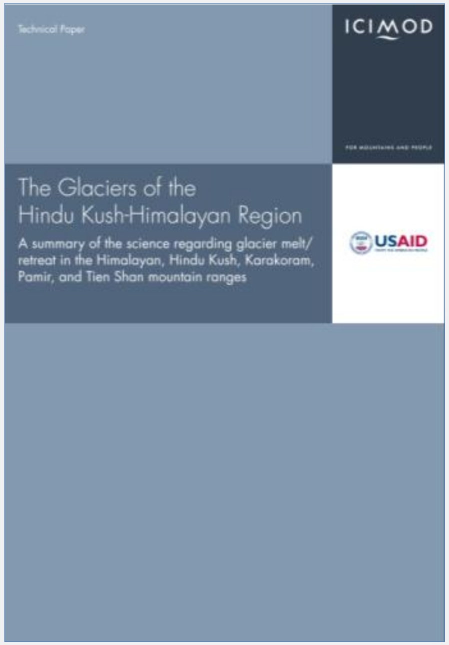
Technical Paper

ICIMOD

The Glaciers of the Hindu Kush-Himalayan Region

A summary of the science regarding glacier melt/retreat in the Himalayan, Hindu Kush, Karakoram, Pamir, and Tien Shan mountain ranges

USAID

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Outline – Changing Glaciers and Hydrology in Asia.

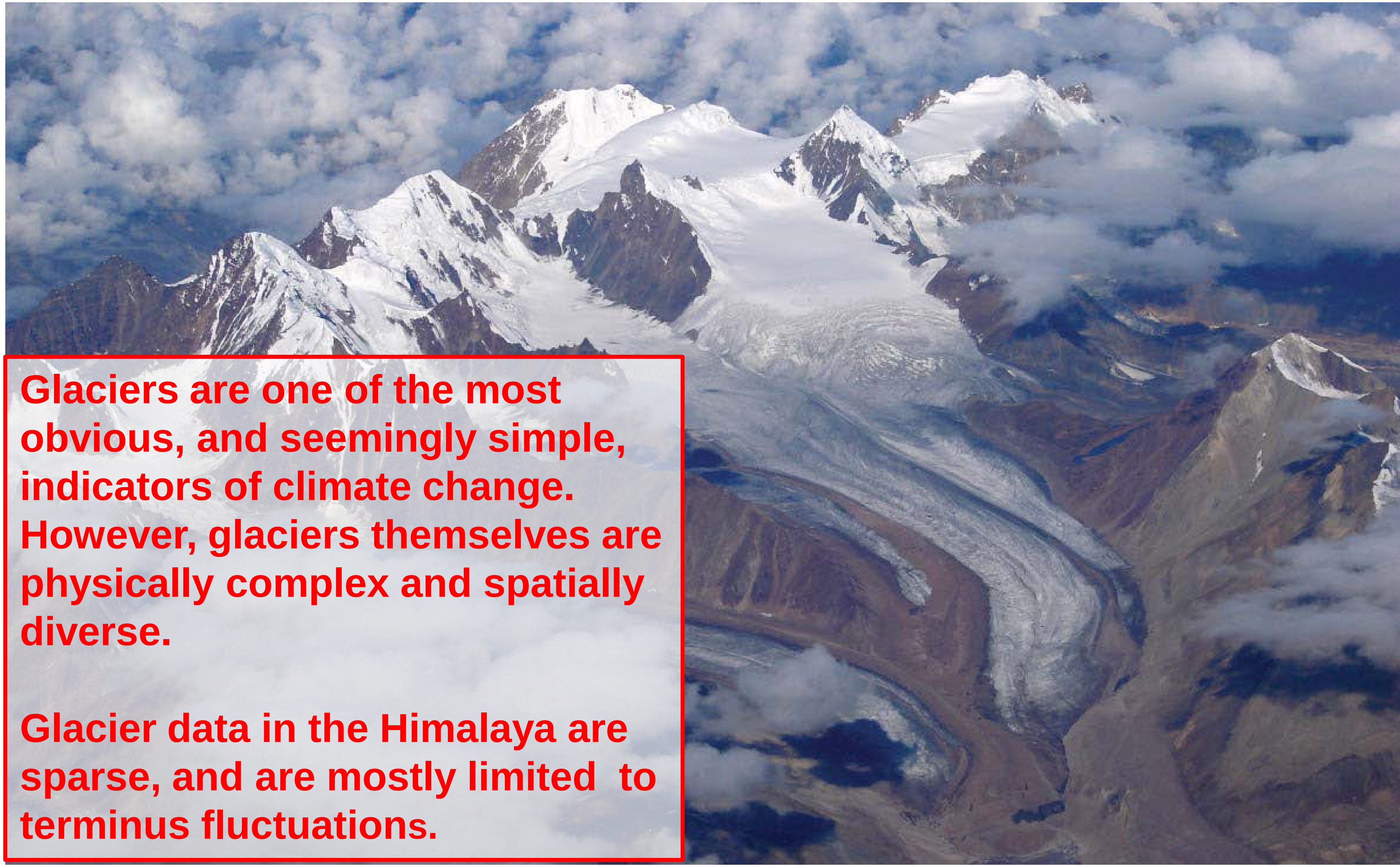
- Glaciology 101

- Glacier fluctuations and recent climate

-Interpretation of glacier mass balance data

-Glacier and climate trends across the greater Himalaya

-What is the relative contribution of glacier ice and seasonal snow melt to river discharge?



Glaciers are one of the most obvious, and seemingly simple, indicators of climate change. However, glaciers themselves are physically complex and spatially diverse.

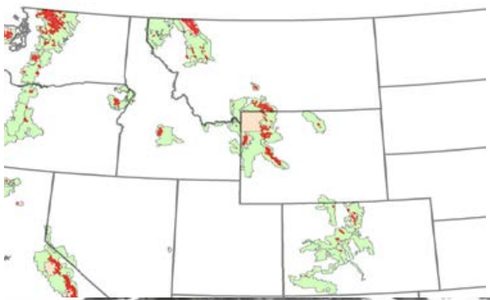
Glacier data in the Himalaya are sparse, and are mostly limited to terminus fluctuations.

Locations such as the European Alps and North America present abundant opportunity to contrast Little Ice Age climate conditions with the present.

An 1870 postcard view of the Rhone glacier in Gletsch, Switzerland, contrasted with the shrinking 21st-century version of it. (Dominic Buettner for The New York Times)

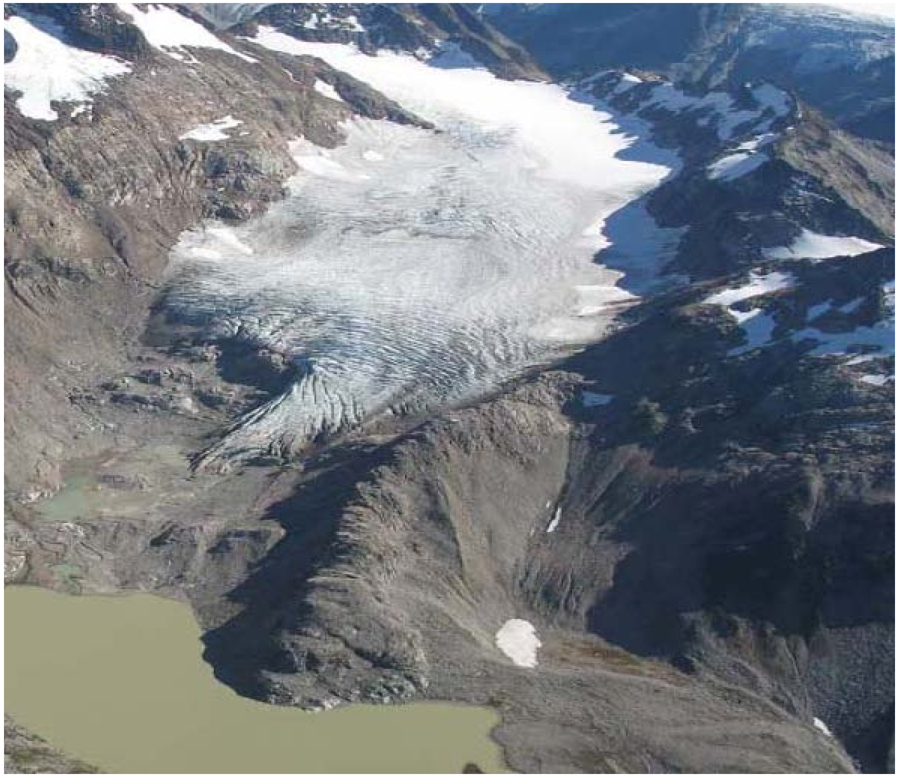
Dramatic statements that glaciers are smaller than they have been for over two hundred years are not particularly surprising or enlightening. Therefore, we focus our attention on the current rate of change.

Location of Glaciers in CONUS



**The fraction of glacier area lost in the Western United States averages ~40% since 1900.
Are such numbers representative of other locations in the world?**

Data from A. Fountain
Portland State University



1960 South Cascade Glacier, Washington 2004

Typical of response of smaller(< 5 km2), low elevation (< 3,500 m), glaciers in North America and Europe to climate warming, however not the case at elevations of 4000-7000 m in the Himalaya

Media reports for the Himalaya often promote misconceptions,

Glaciers are melting !!!! – (a normal seasonal process)

Glaciers are melting (disappearing) rapidly – (given a warming climate, true in many locations, but likely not all)

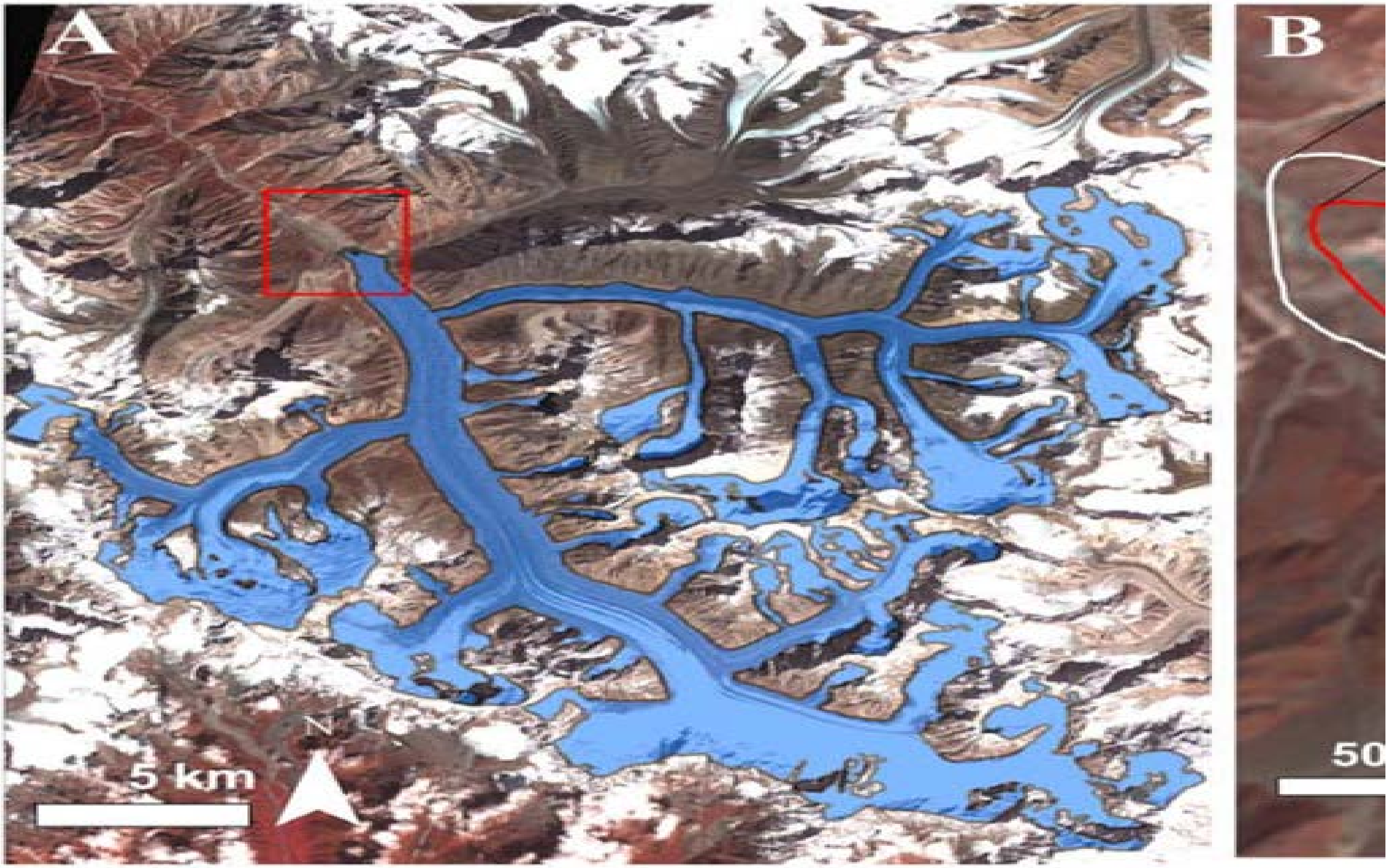
Glaciers are melting faster than anywhere else in the world – (not supported by actual data)

and, if this rapid melting continues, rivers will first flood and then dry up. (makes no physical sense),

or become seasonal (they already are seasonal)

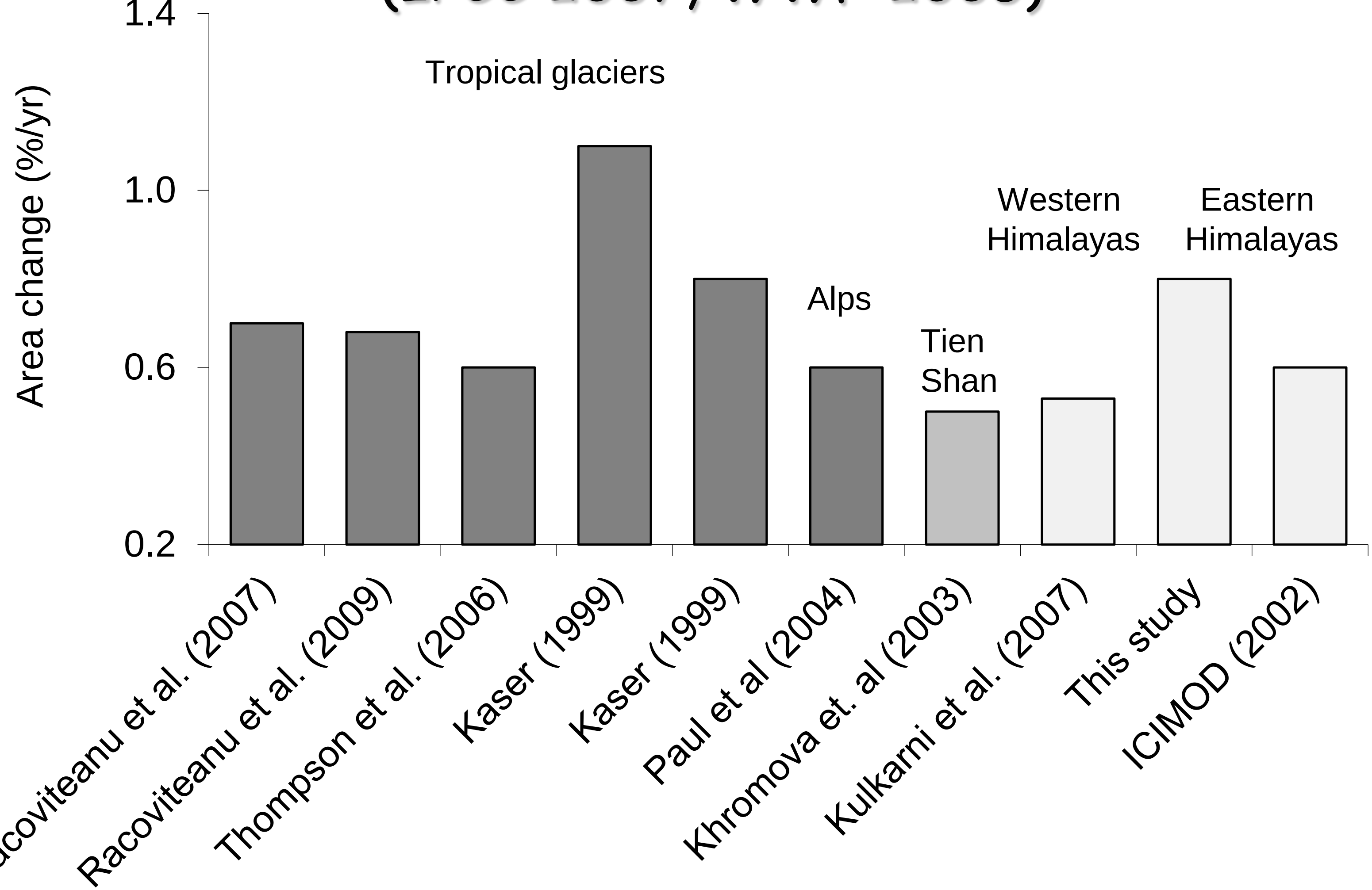
There is much more to the "story" - a clear need to reduce un-certainty by bridging some of the more significant data gaps.

Glacier data are sparse and mostly limited to terminus fluctuations.



Terminus Location History- Gangotri Glacier, Uttarkashi district of Garhwal Himalaya, India (Kargel et al. PNAS, 2011)
(a point measurement to assess the behavior of a large system is problematic)

Are Himalayan glaciers retreating faster than in any other mountain ranges? (IPCC 2007, WWF 2005)



Examples appear to be limited to lower elevation glaciers of the Eastern Himalaya.

Revised and adapted from Racoviteanu et al, J Glaciol, 2008

Understanding Glacier Retreat -

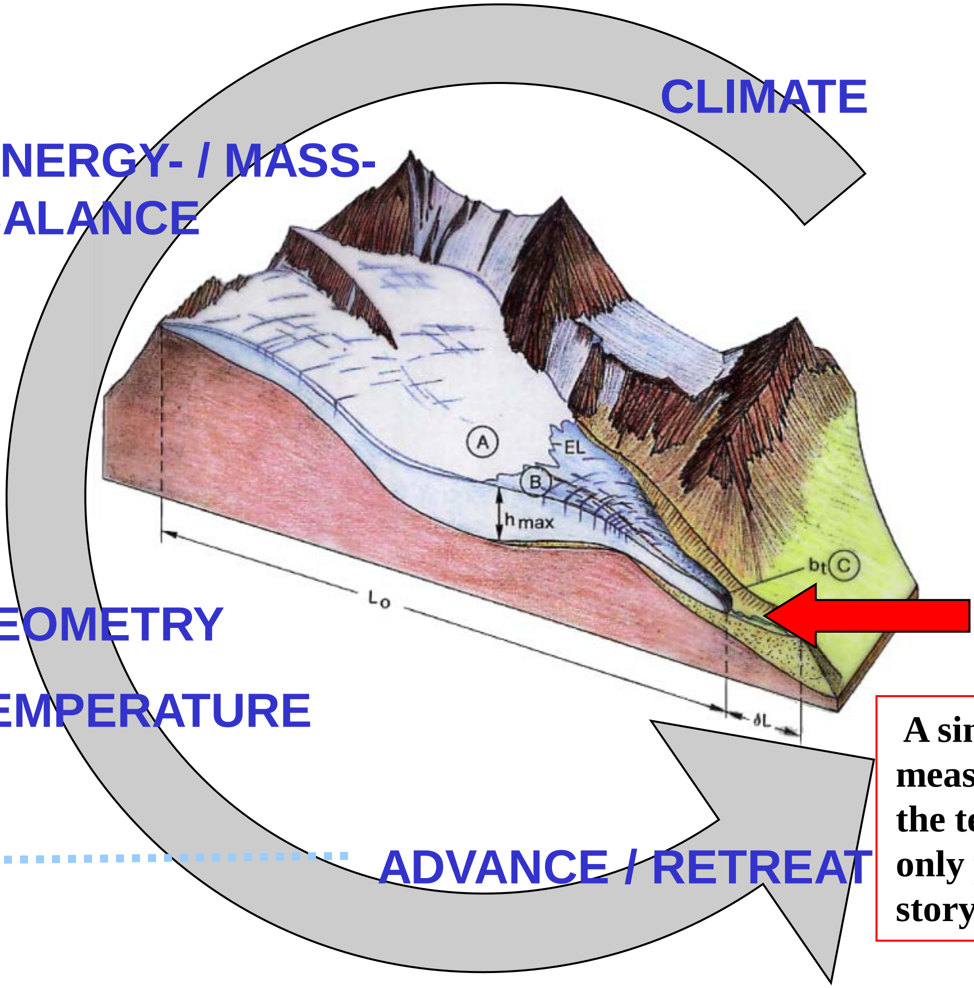
* Retreating glacier = terminus is melting faster than the rate at which ice is being supplied to that location by movement of ice from further upslope in the system.

* It is possible that while the terminus of a glacier is retreating the total mass of the same glacier may be increasing from one year to the next due to increasing amounts of snow arriving at the higher elevations of the glacier from precipitation, wind deposition, and avalanching.

* Certainly, however, when glaciers are observed to have been in consistent retreat over decades, they are not in balance with the recent climate.

Climate-glacier-dynamics process chain

direct, undelayed signal



A single, local, measurement at the terminus is only part of the story.

indirect, delayed, filtered and enhanced signal

Haeberli (1998)

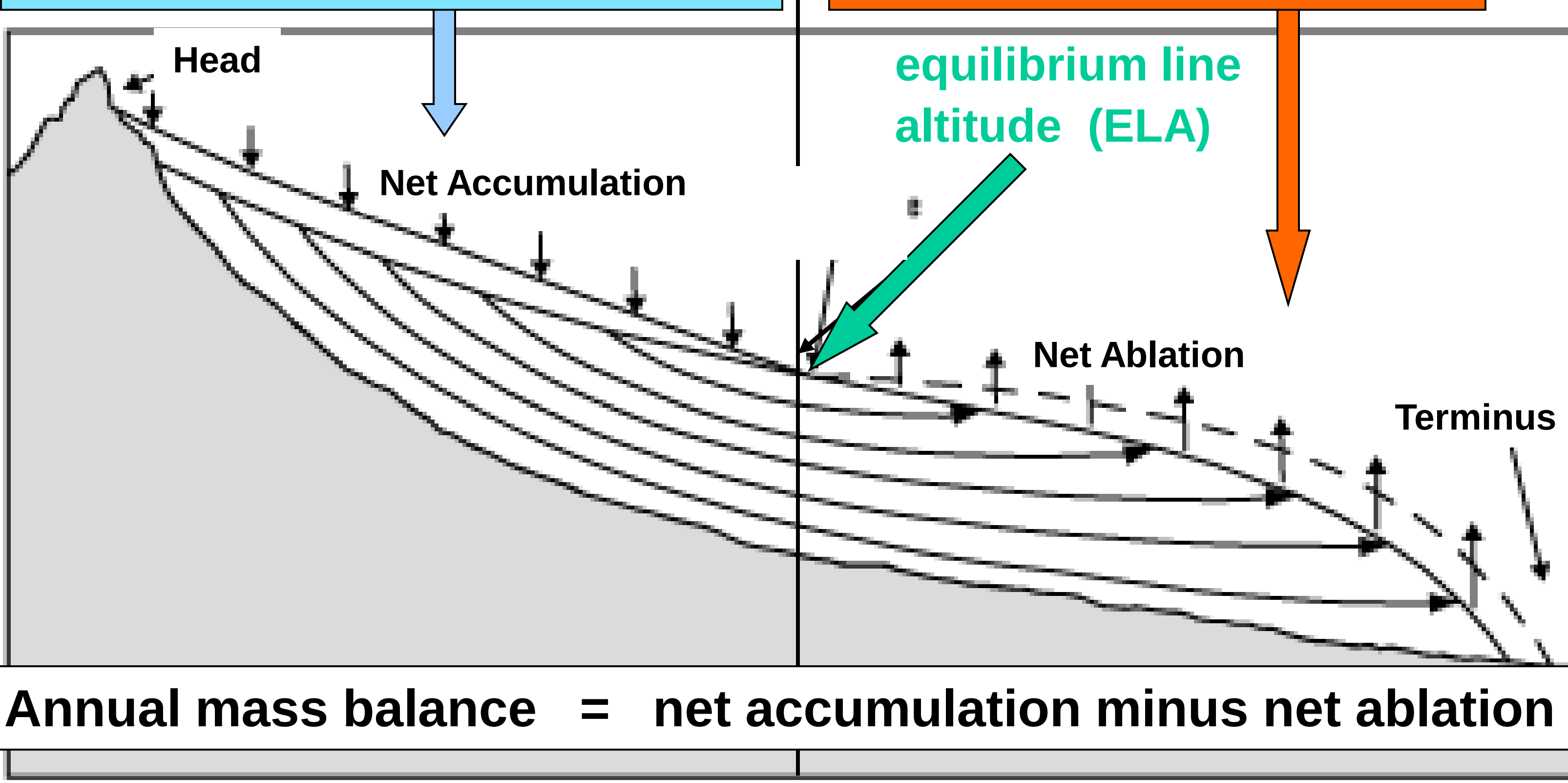
Response time for Himalayan glaciers on the order of decades to centuries.

Glacier Mass Balance

A more direct and comprehensive measure of the "health" of a glacier

Accumulation Area

Ablation Area



Annual mass balance = net accumulation minus net ablation

Nepal Himalayas

"Glacier AX010 to disappear by 2060?

- ***Reasonable? --- Perhaps***
- **Small (~ 0.5 km^2)**
- **Altitude range: 4952 – 5381m below regional Equilibrium Line Altitude (ELA)**
- **Not representative regionally**

(a)

(b)

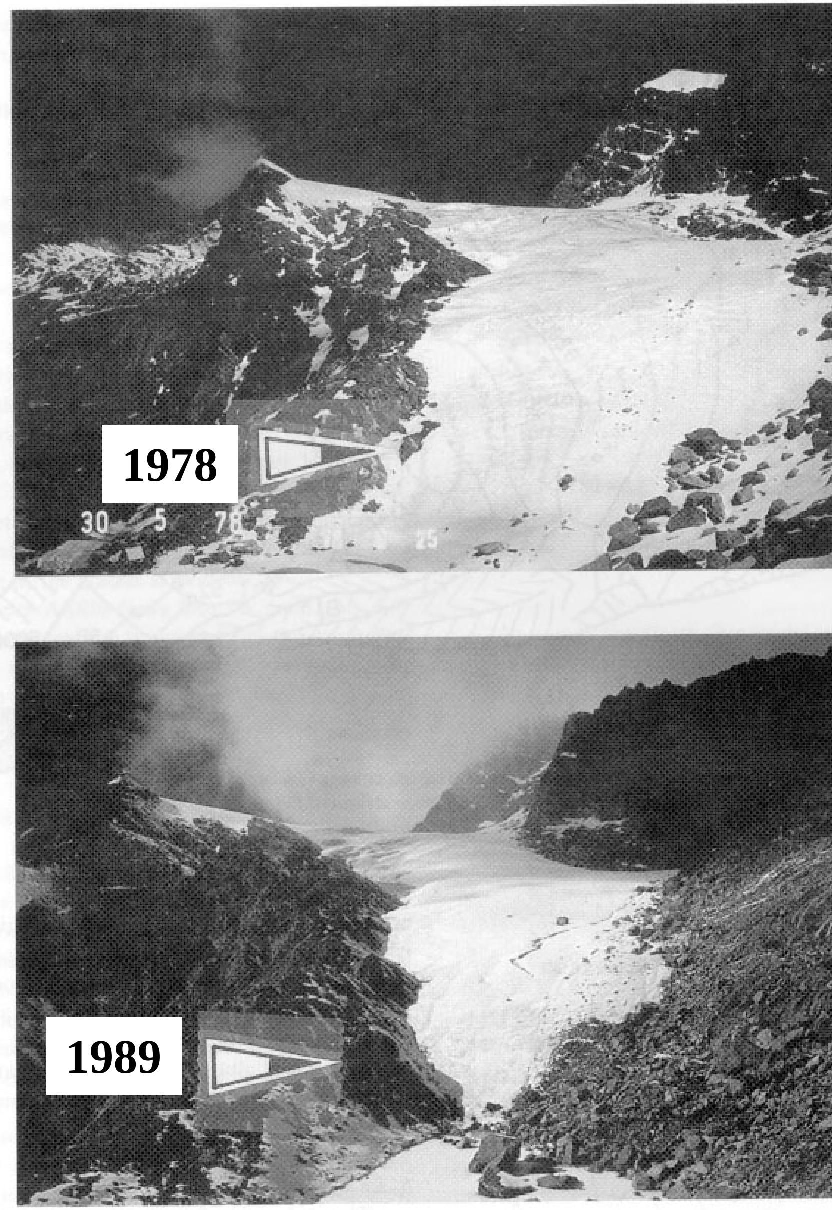
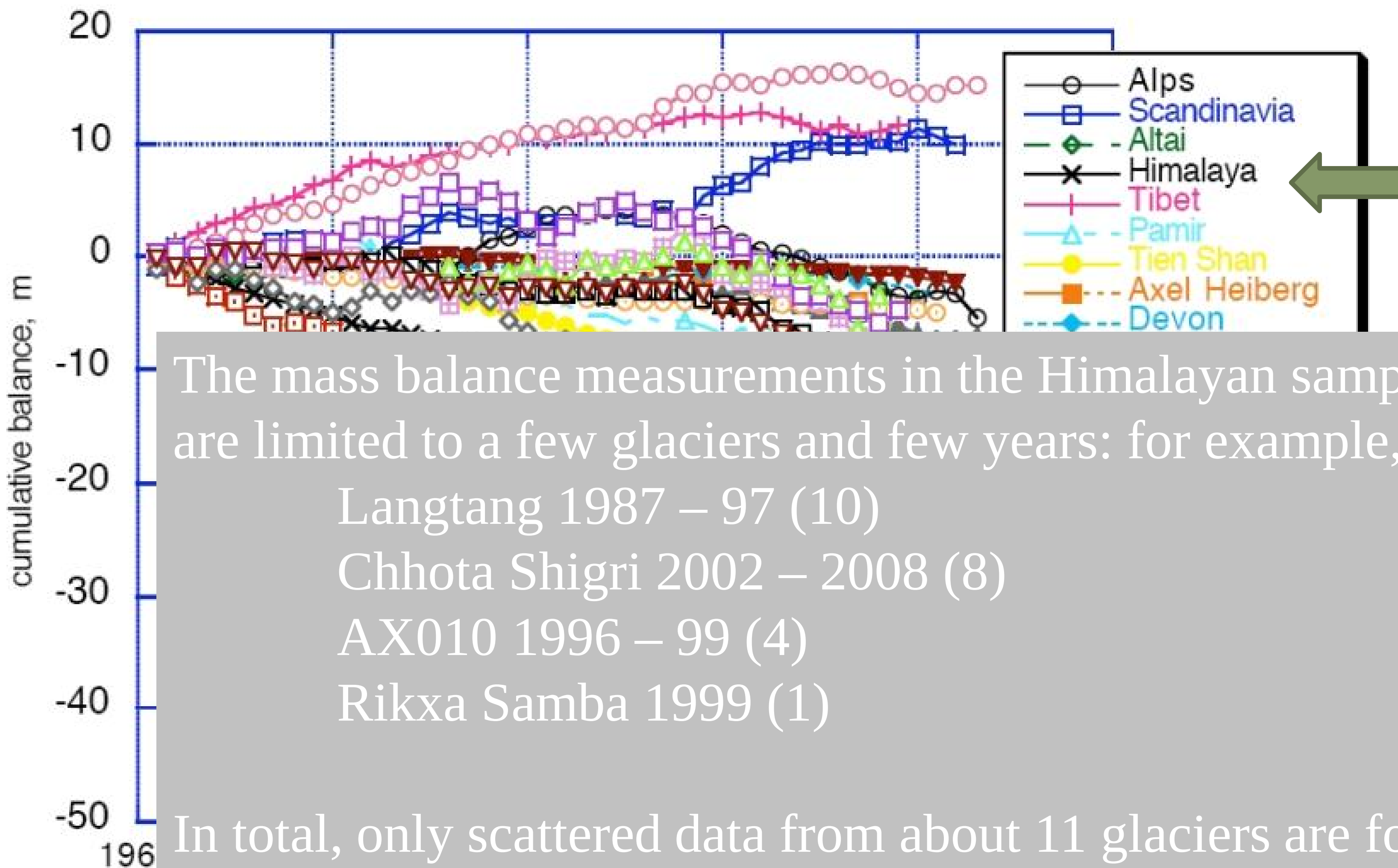


Fig. 4. Photographs of the lower part of Glacier AX010 taken in June 1978 (a), and in November 1989 (b). Shrinkage of the glacier is evident as shown by arrows in (a) and (b) at the same point.

Cumulative mass balances of selected glacier systems compiled from individual time series. Dyurgerov, 2005 INSTAAR OP58



The mass balance measurements in the Himalayan sample are limited to a few glaciers and few years: for example, -

Langtang 1987 – 97 (10)

Chhota Shigri 2002 – 2008 (8)

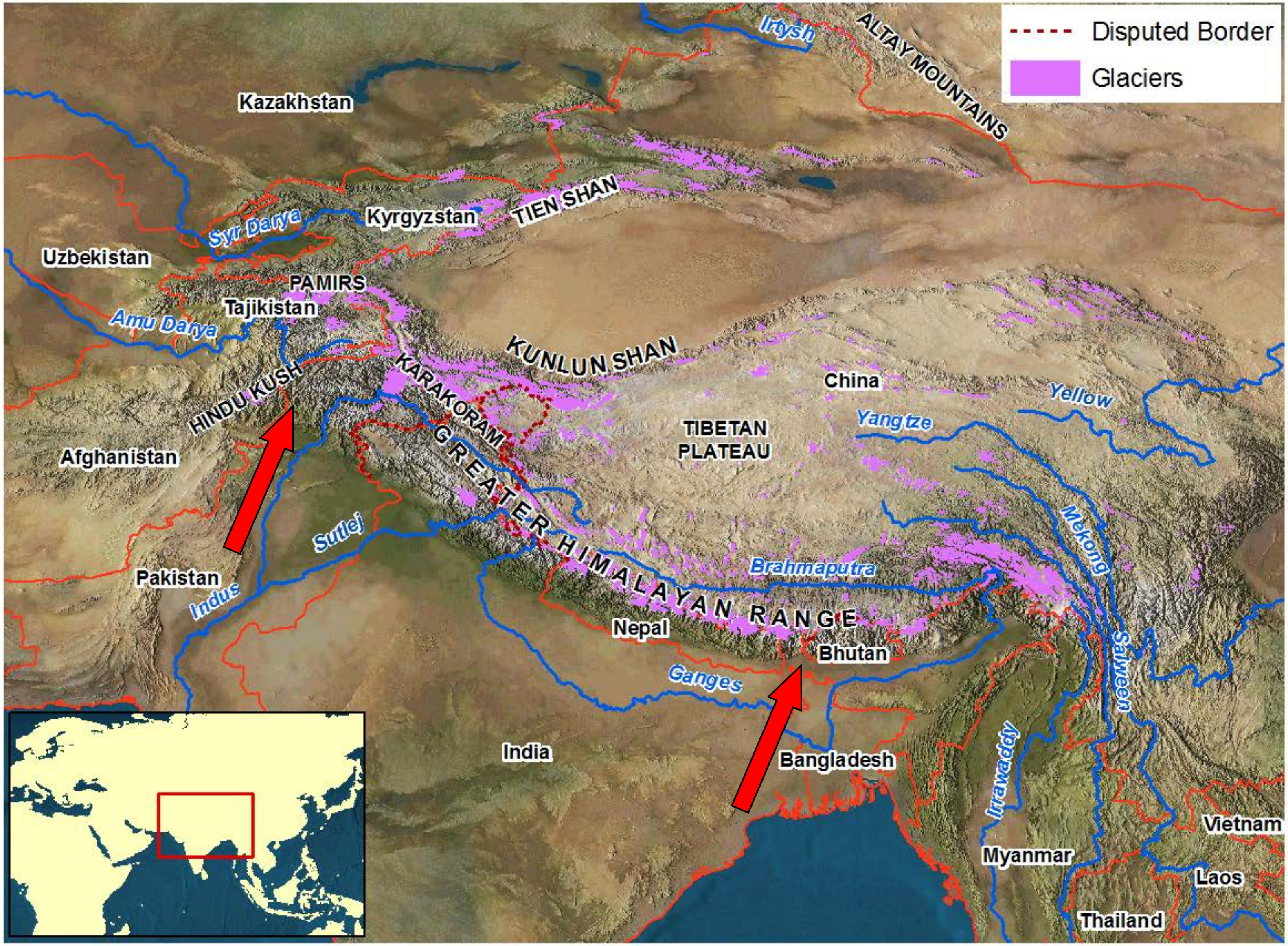
AX010 1996 – 99 (4)

Rikxa Samba 1999 (1)

In total, only scattered data from about 11 glaciers are found in WGMS data base, but only one, Langtang, with a maximum elevation above the current regional ELA.

Presentati

data in the



Contrasting conditions east to west stress the importance of implementing <u>spatially comprehensive assessments</u>.

The East-West Climate Pattern of the Himalaya, Karakoram, Hindu Kush

A 2000 kilometer arc from eastern Nepal and Bhutan to northern Afghanistan. Increase in latitude and mean elevation.

Precipitation and basin runoff decrease from the east to west as a result of the weakening effect of the summer monsoon.

Variation in runoff with elevation: Nepal, maximum runoff being generated at approximately 3,000 m, with decreasing amounts at both lower and higher elevations, regions further west indicate more linear gradients steadily increasing up to 5,000-6,000 m.

Implies that snow cover and glaciers in the western Himalaya, the Karakoram, and Hindu Kush, are increasingly important sources of streamflow volume. Previous estimates have varied greatly.

However, total runoff in the western mountains is considerable less than that in the east at all altitudes, which is to be expected given the aridity of the region.

The East-West Climate Pattern - contd.

Temperature and Precipitation Trends -

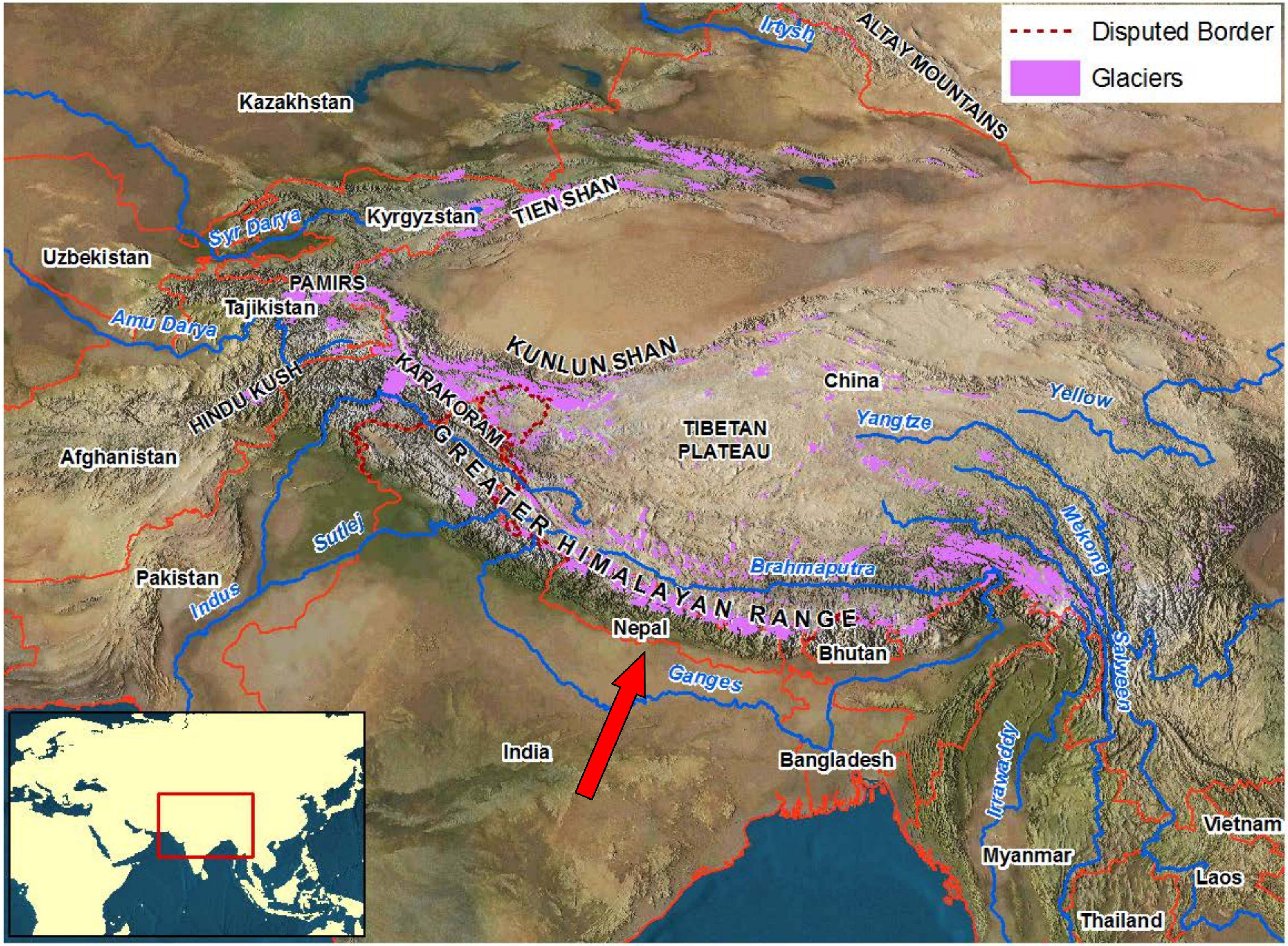
Air temperature trends over the past few decades vary across the region. Increases of 0.06 to 0.12 deg. C per year for the eastern Himalaya, along with decreased precipitation.

In contrast, the Karakoram range in the west is reported to have experienced decreasing maximum and minimum temperatures, along with increased precipitation.

Glaciers –

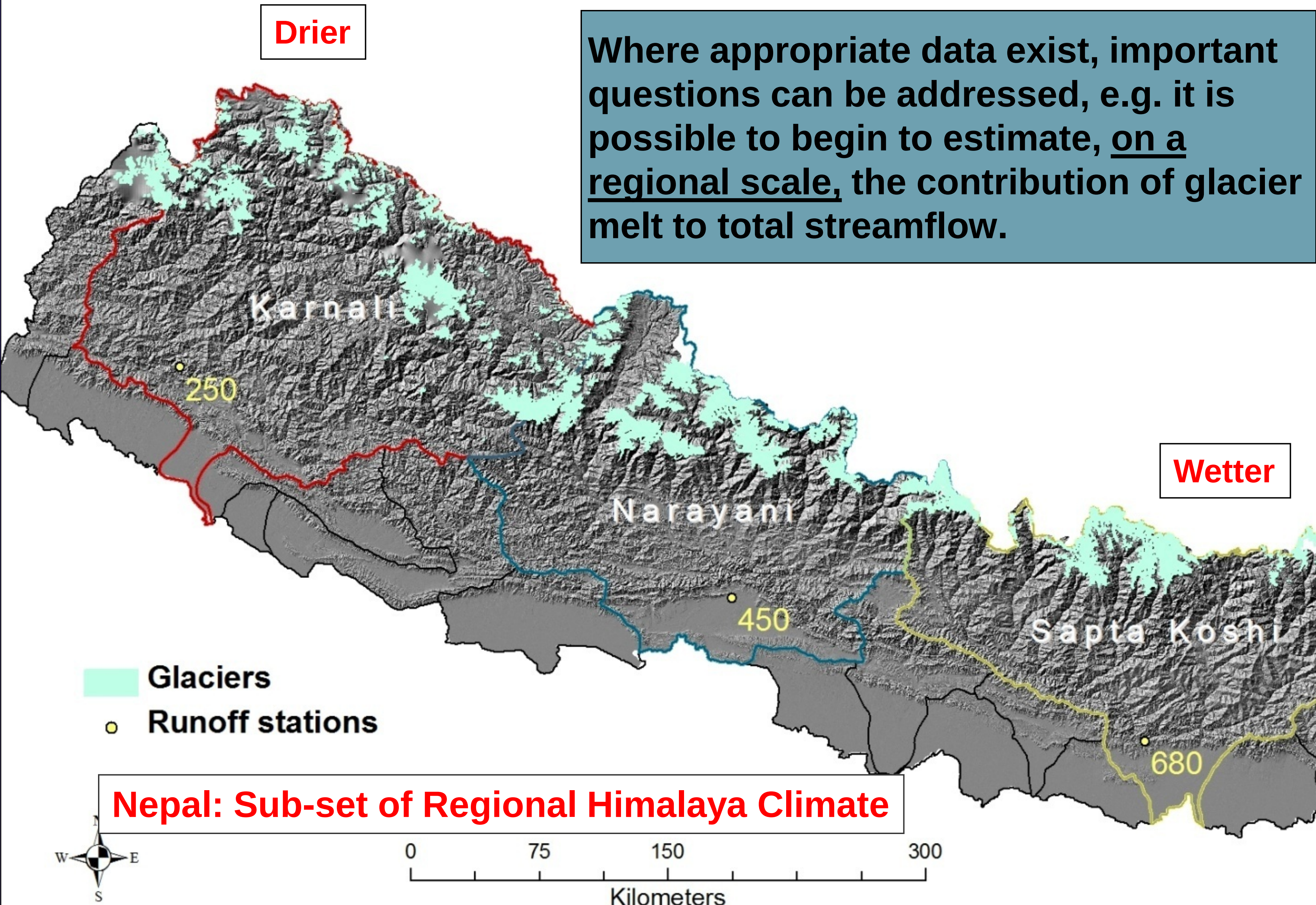
Accumulation and ablation patterns are distinctly different:
East = summer season includes both max accumulation and max melt.
West = general pattern of summer melt and winter accumulation.

Climate response: the west appears to show slower rates of retreat, less formation of pro-glacial lakes associated with flood hazard, and some observations of advancing glaciers, in contrast to the eastern region.



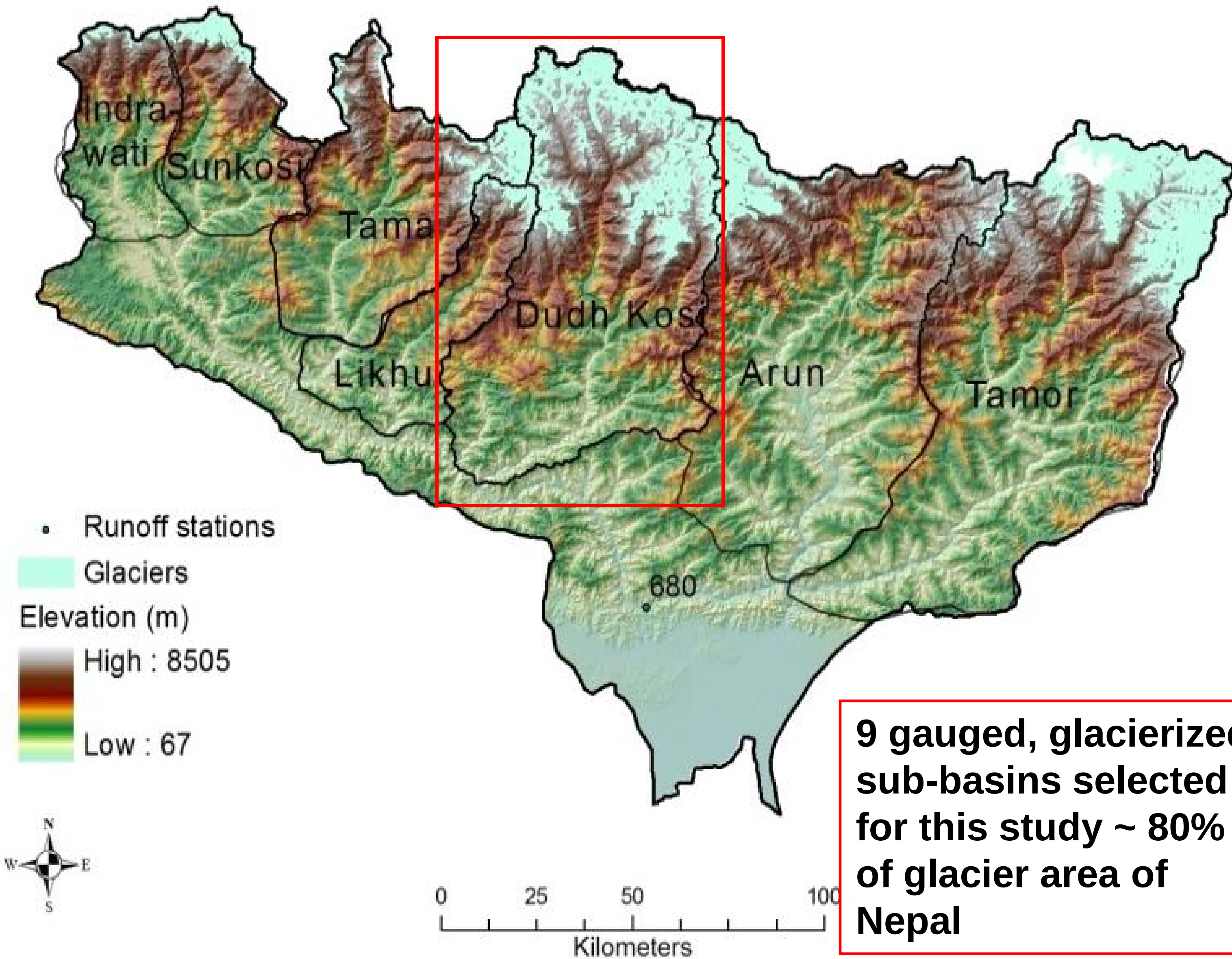
Eastern Himalayan Range - Nepal

Where appropriate data exist, important questions can be addressed, e.g. it is possible to begin to estimate, <u>on a regional scale,</u> the contribution of glacier melt to total streamflow.



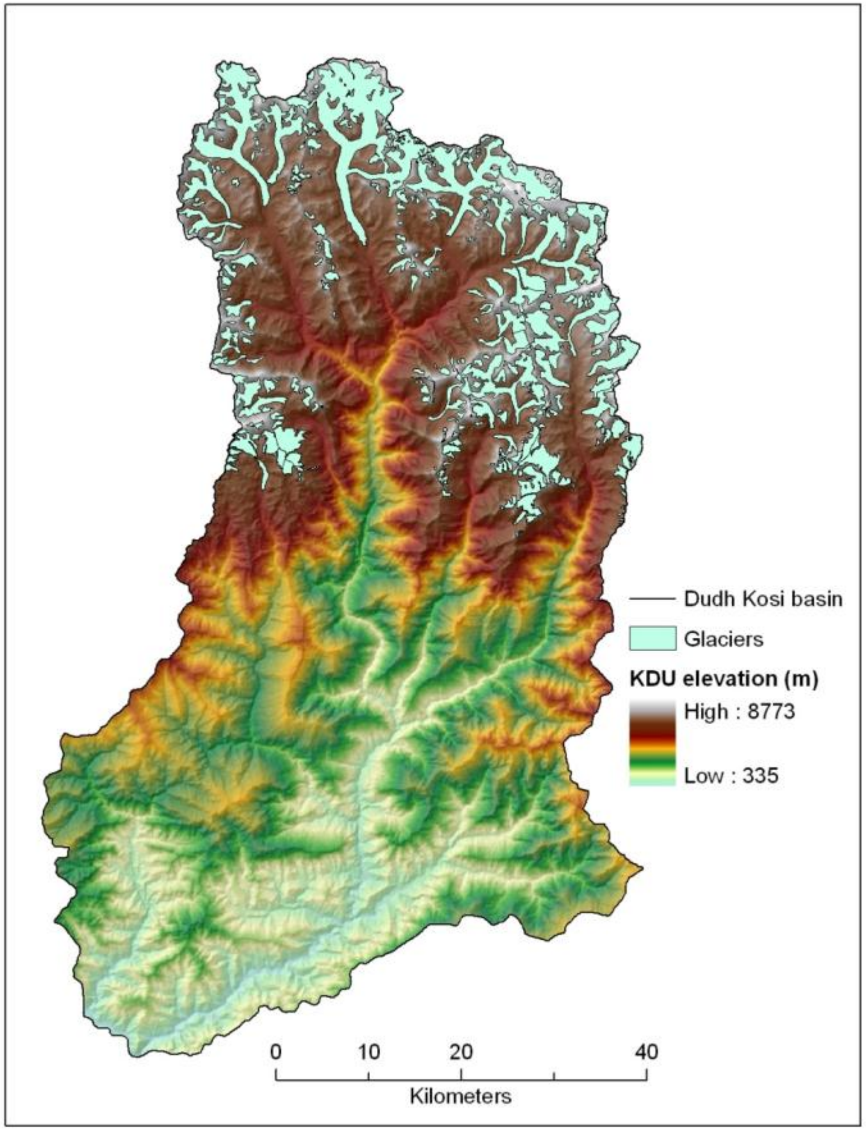
Nepal: Sub-set of Regional Himalaya Climate

SAPTA KOSI BASIN



9 gauged, glacierized sub-basins selected for this study ~ 80% of glacier area of Nepal

Data Sources



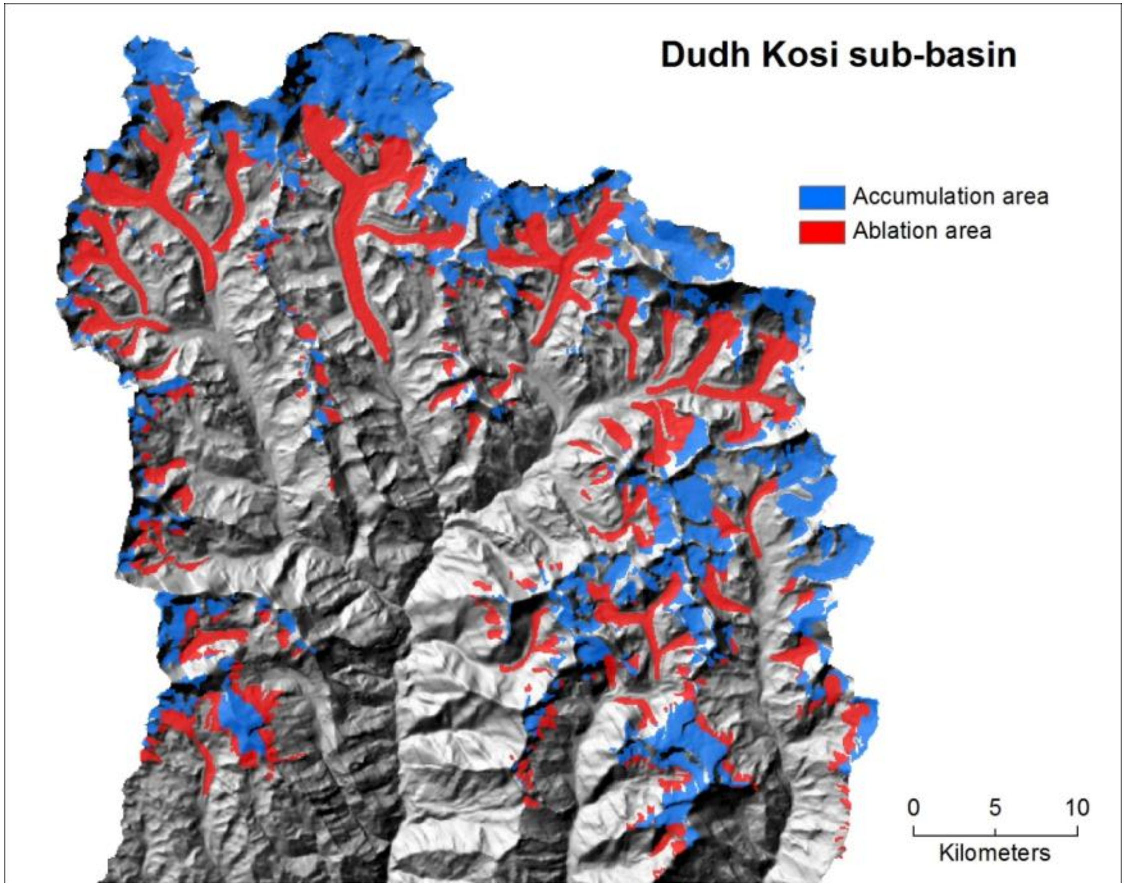
- Digital elevation model (DEM) from the NASA Shuttle Radar Topography Mission (SRTM v.4) (90m spatial resolution).

- Glacier outlines for Nepal from topographic maps and satellite data (ICIMOD /GLIMS)

- Catchment basins from ICIMOD (basic topographic unit in water budget analysis)

-Runoff data from Department of Hydrology and Meteorology (DHM) Nepal

Define Accumulation and Ablation Areas to Support an Area-Altitude-based Ice Melt Model

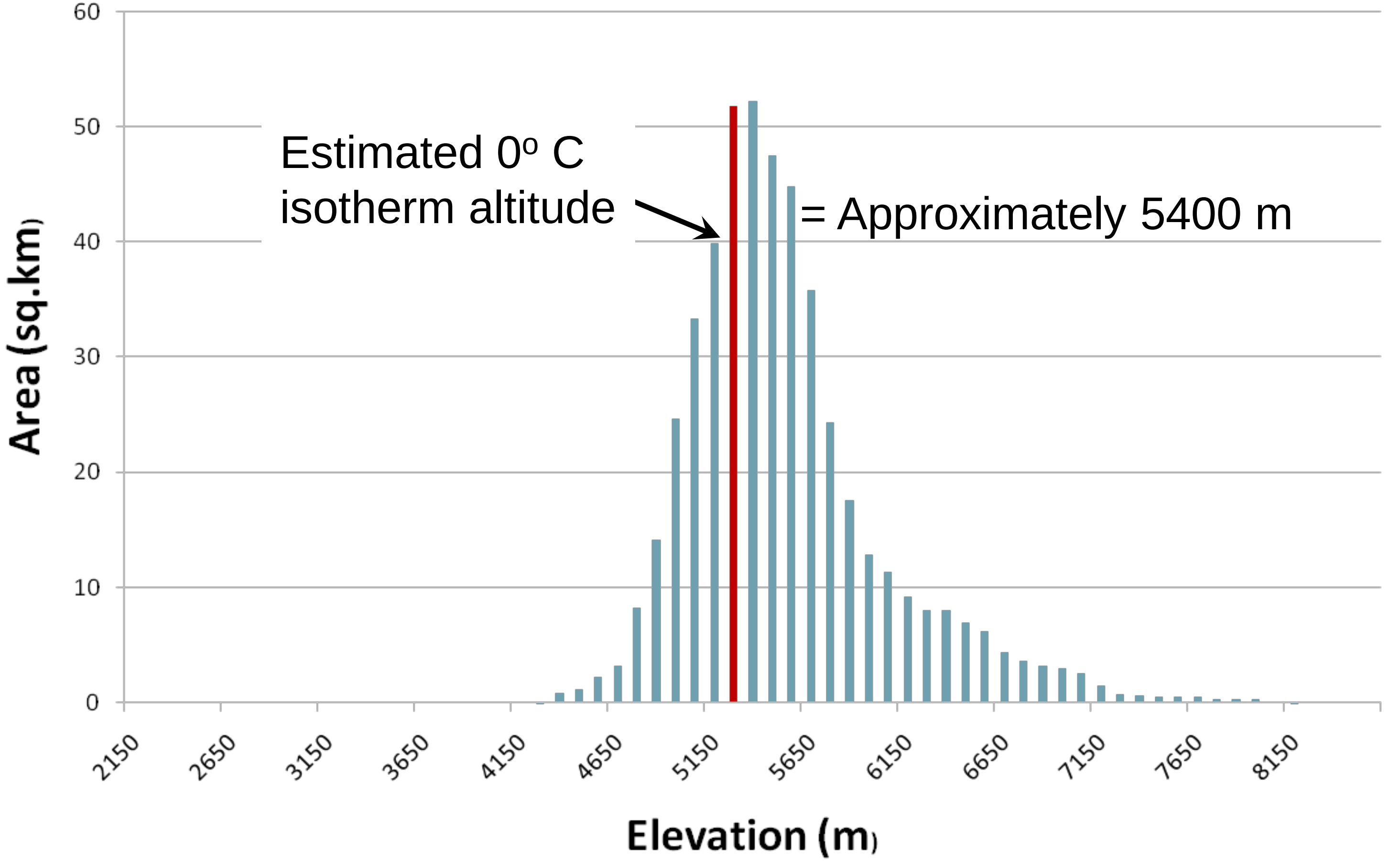


Let the regional 0 º isotherm represent the Equilibrium Line Altitude (ELA)

Estimate the mean monthly altitude of the 0 deg C. isotherm during the summer season by extrapolation from lower elevation met stations and NCEP reanalysis upper air data.

Estimated to be ~ 5400m

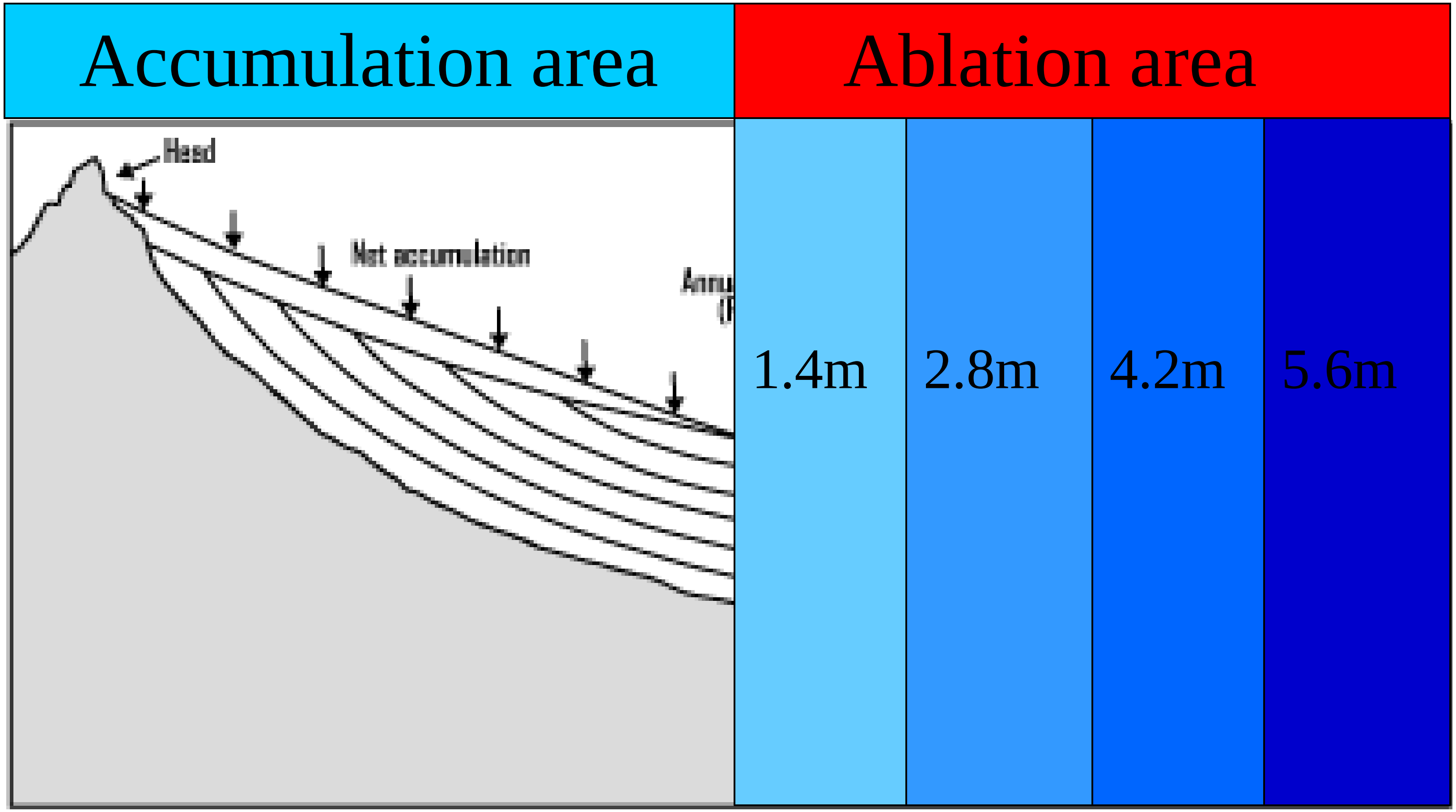
Glacier covered area of Dudh Kosi Basin, Nepal
Example of area/altitude hypsometry and location of 0º isotherm



Compute melt below 5400 m using a regional vertical mass balance gradient.

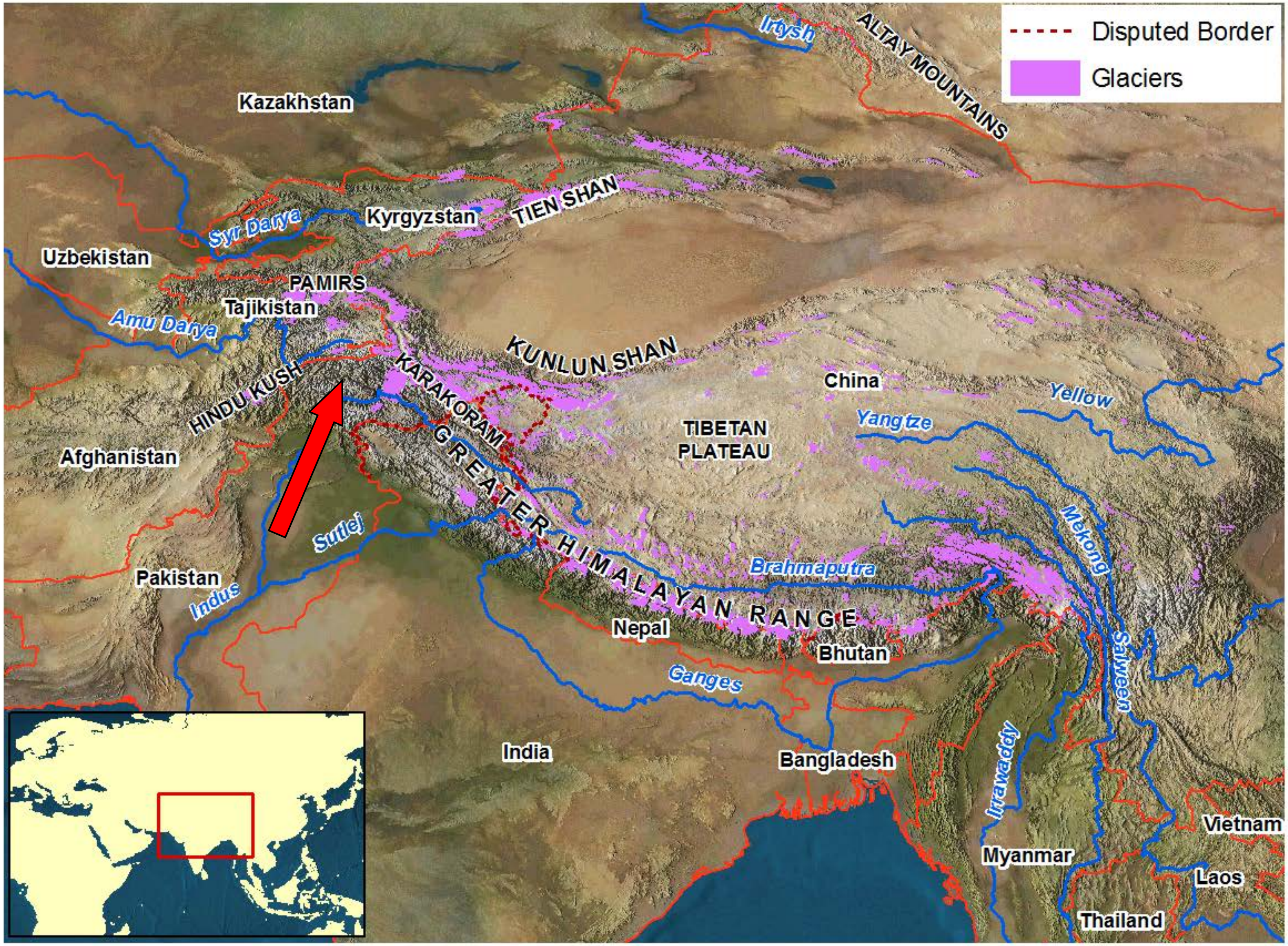
Compute runoff from melting glacier ice –

Volume = sum of the products of the specific net budget within the (100 m) elevation bands of the ablation zone and surface area of those elevation bands. In this study: db/dz = 1.4 m/ 100m for probable maximum runoff volume from ice melt for the region.



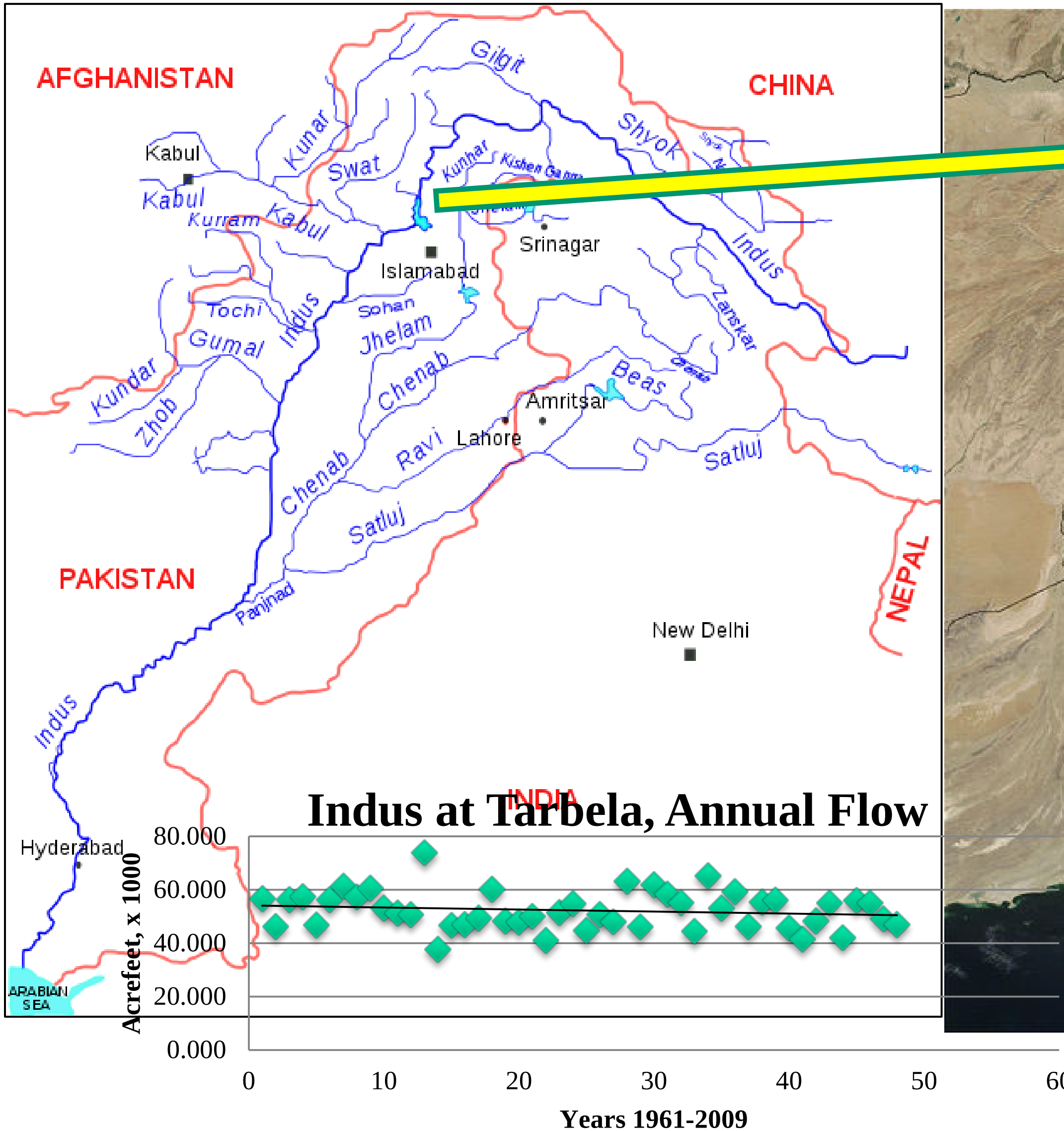
Results of Nepal Study

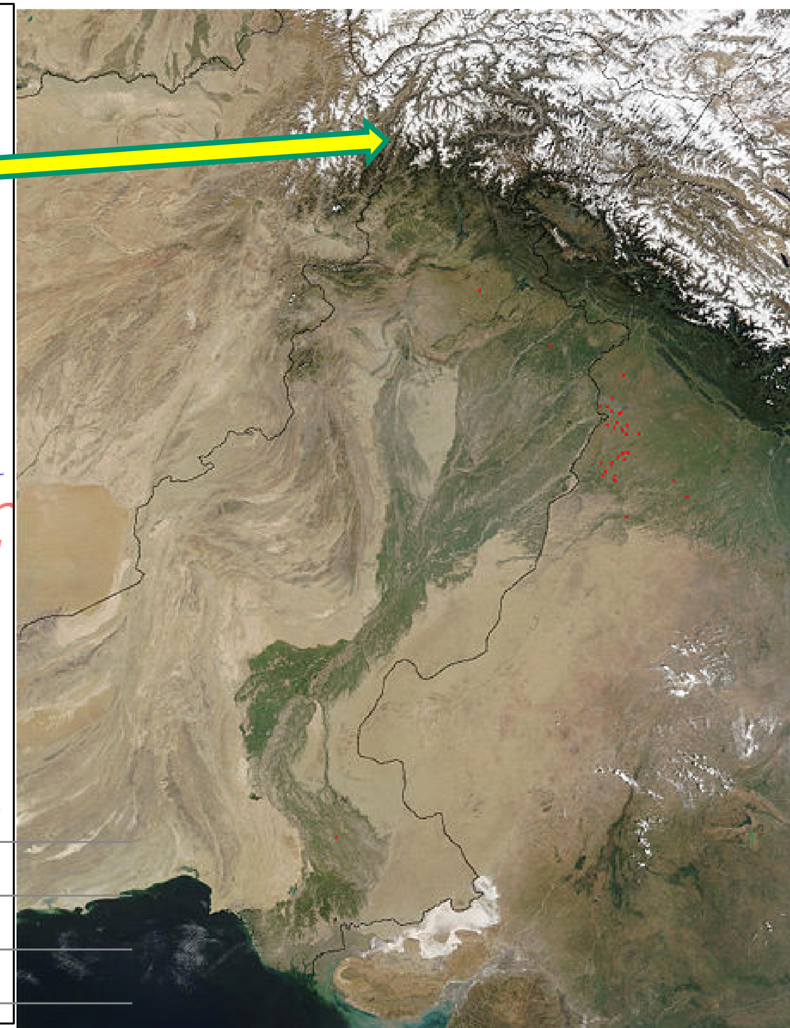
- The contribution of glacier ice melt to annual streamflow volume varies among the 9 sub-basins from approximately 2-30%.
- This glacier melt contribution is estimated to be about 4% of the total mean annual streamflow volume of the rivers flowing out of Nepal.
- Mass balance gradient and degree day melt models produce comparable results.
- Similar results were reported by Thayyen and Gergan in The Cryosphere 4, 2010 for the Dokriani glacier, Nepal.

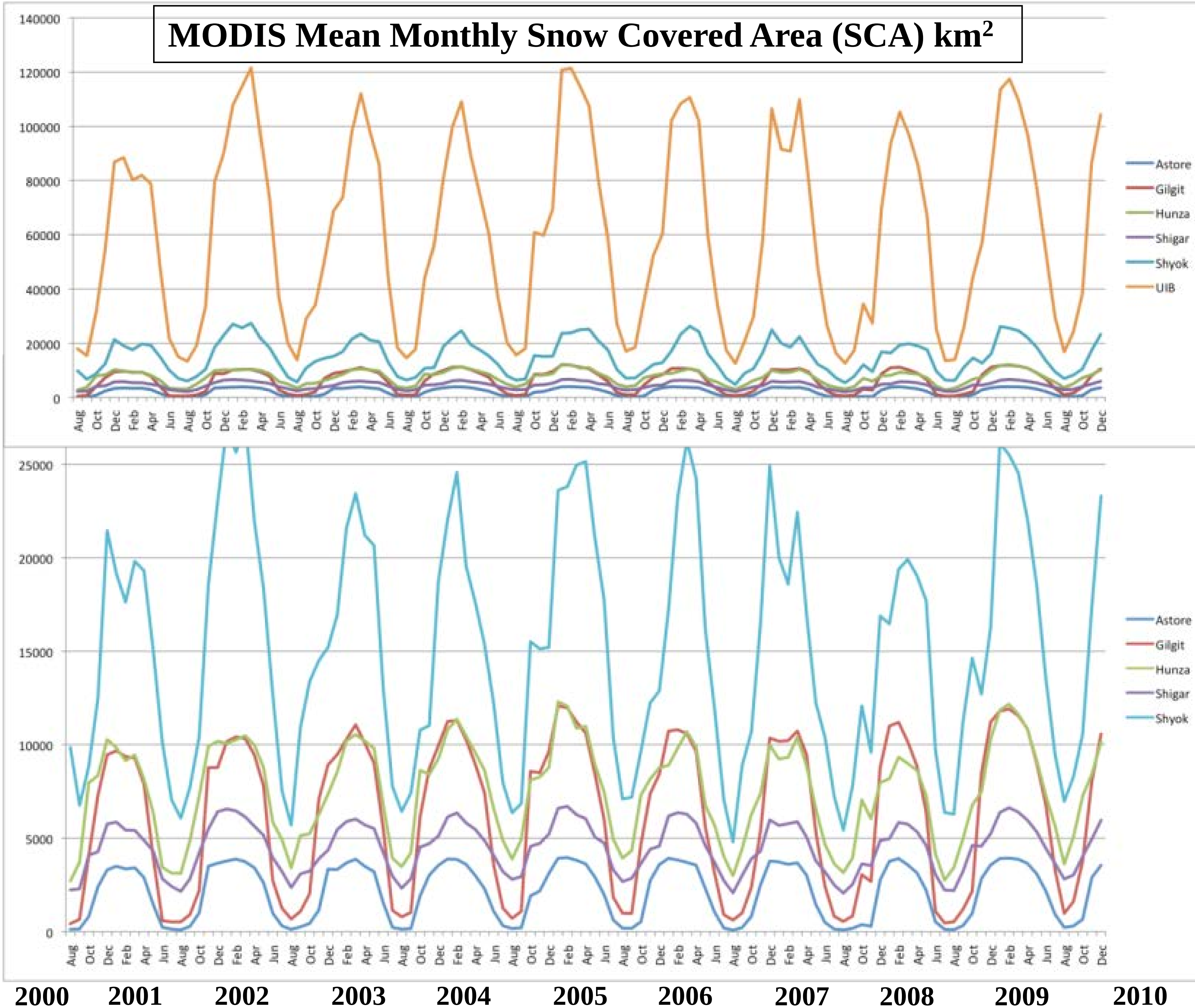


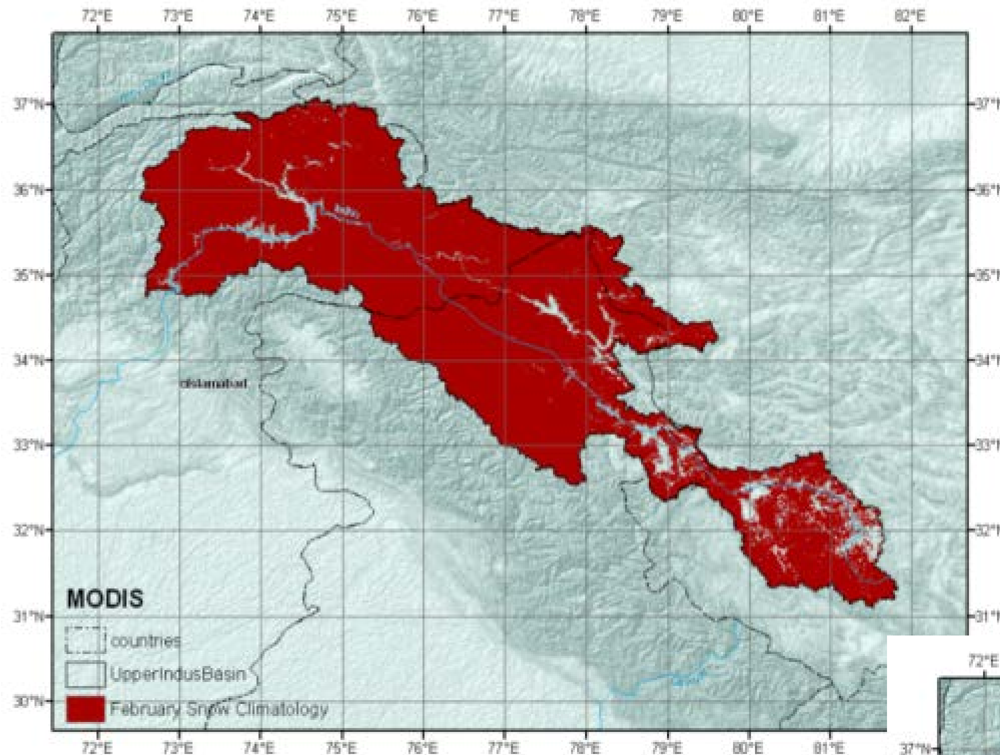
Western Himalaya, Karkoram, Hindu Kush, Pamirs

Approximately 80-90% of the flow of the Indus at Tarbela has been estimated to originate as seasonal snow and glacier ice melt. But in what proportion?





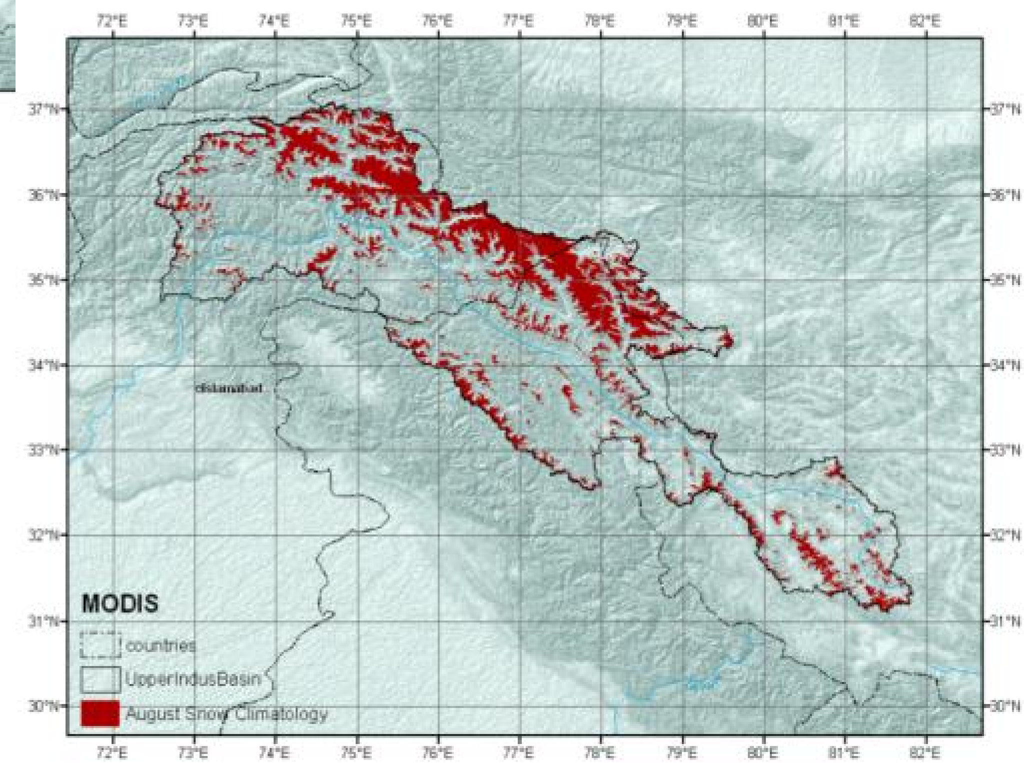

MODIS Mean Monthly Snow Covered Area (SCA) km²
140000
120000
100000
80000
60000
40000
20000
0
Astore
Gilgit
Hunza
Shigar
Shyok
UIB
25000
20000
15000
10000
5000
0
Astore
Gilgit
Hunza
Shigar
Shyok
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

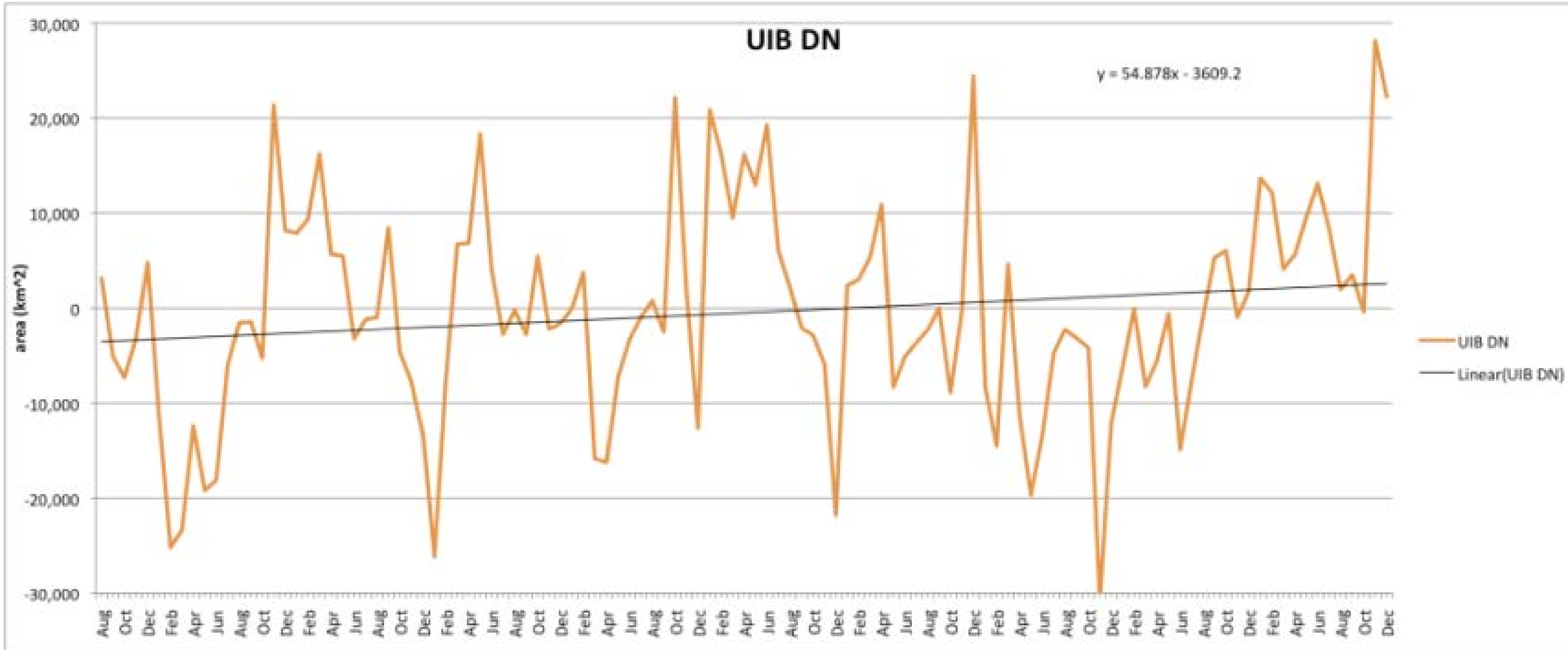


Upper Indus Basin Seasonal Snow Area

February – annual maximum seasonal snow cover

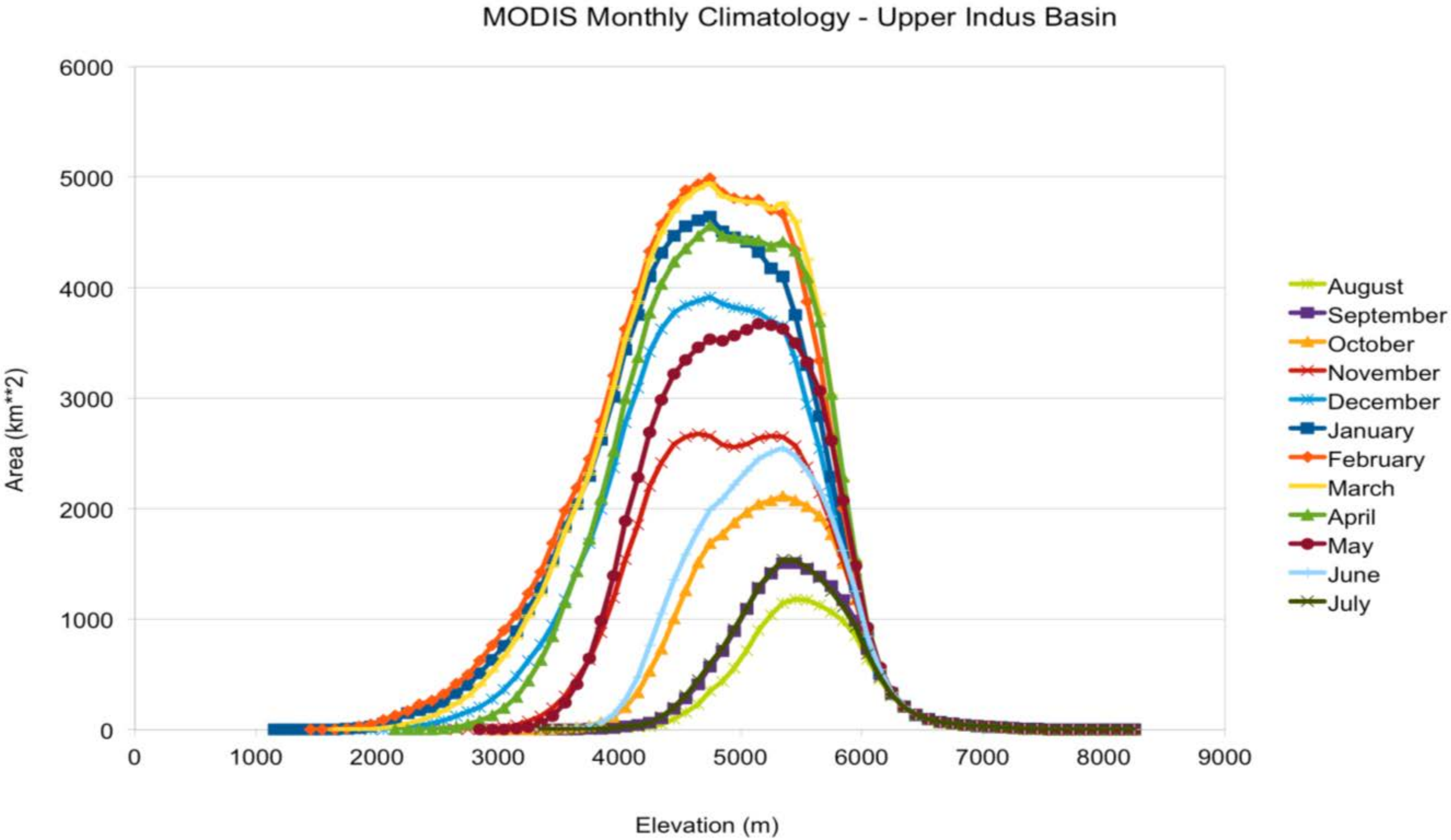
August – annual minimum, semi-permanent snow and glaciers





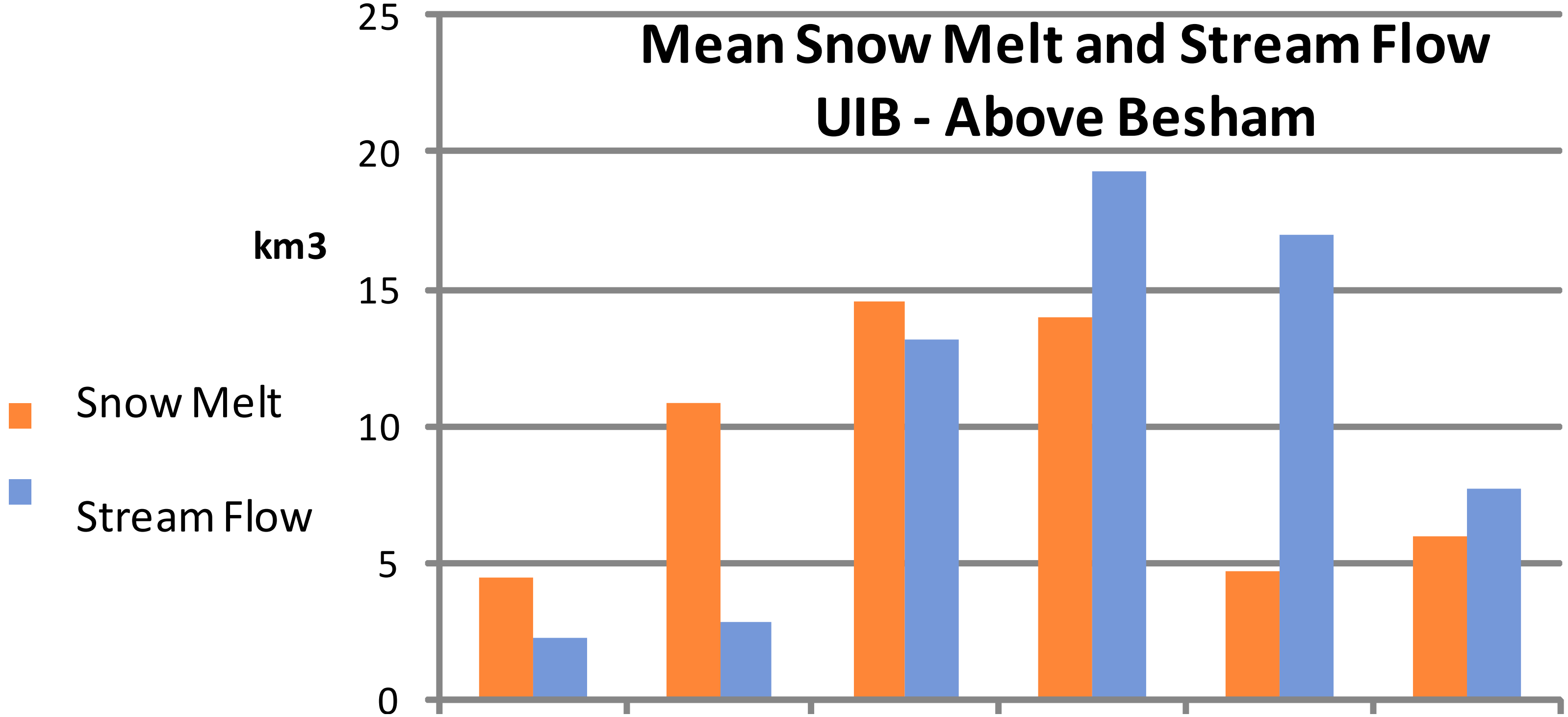
2000 → **2010**

Departures from the MODIS mean snow covered area for the full UIB.



Mean monthly area-elevations for seasonal snow cover in the UIB.

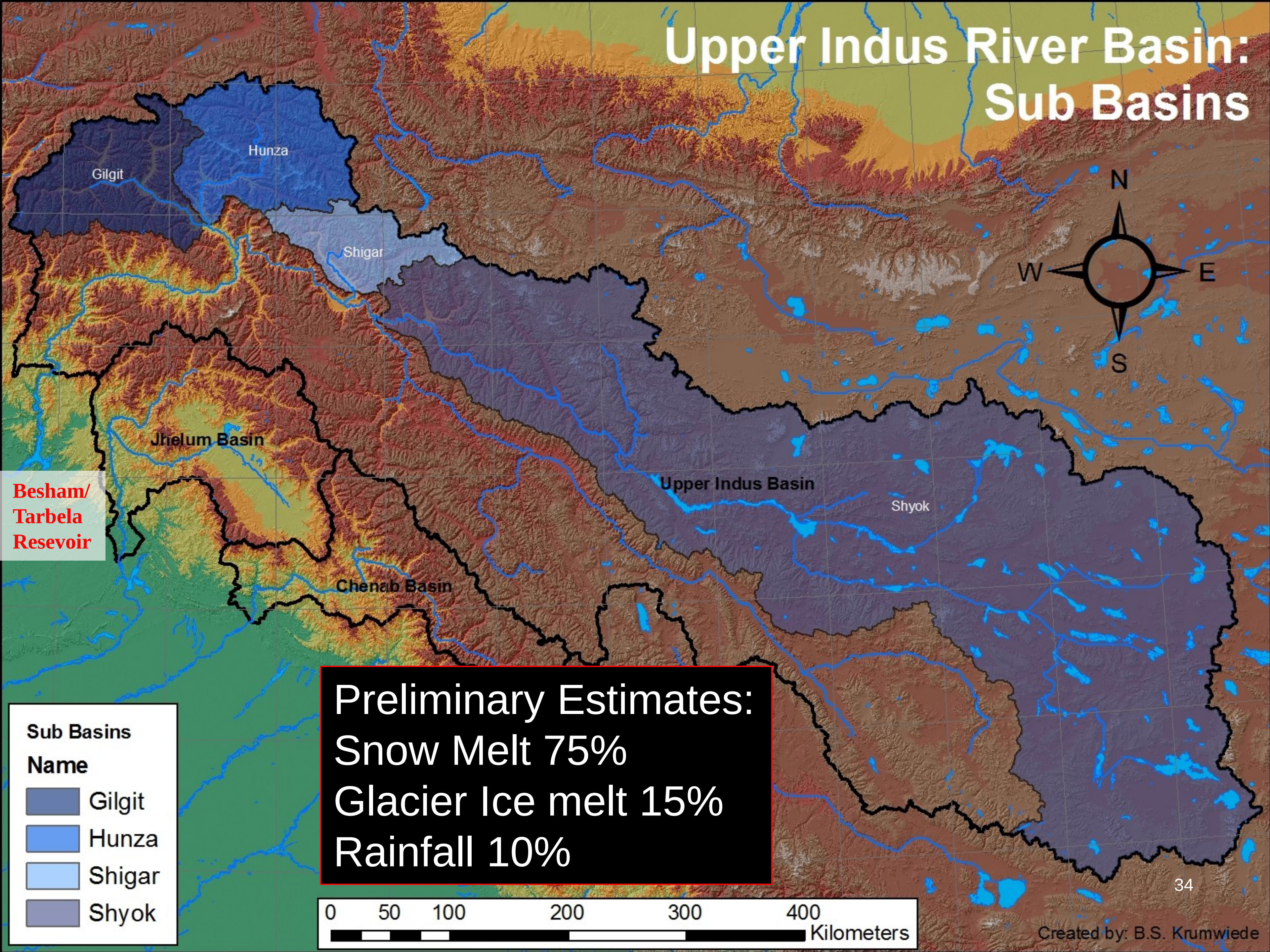
Armstrong, NSIDC/U. of Colorado



	April	May	June	July	August	Sept
Snow Melt	4.5	10.8	14.5	14	4.7	6
Stream Flow	2.2	2.8	13.1	19.3	17	7.7

Armstrong, NSIDC/U. of Colorado

Upper Indus River Basin: Sub Basins



Preliminary Estimates:
Snow Melt 75%
Glacier Ice melt 15%
Rainfall 10%

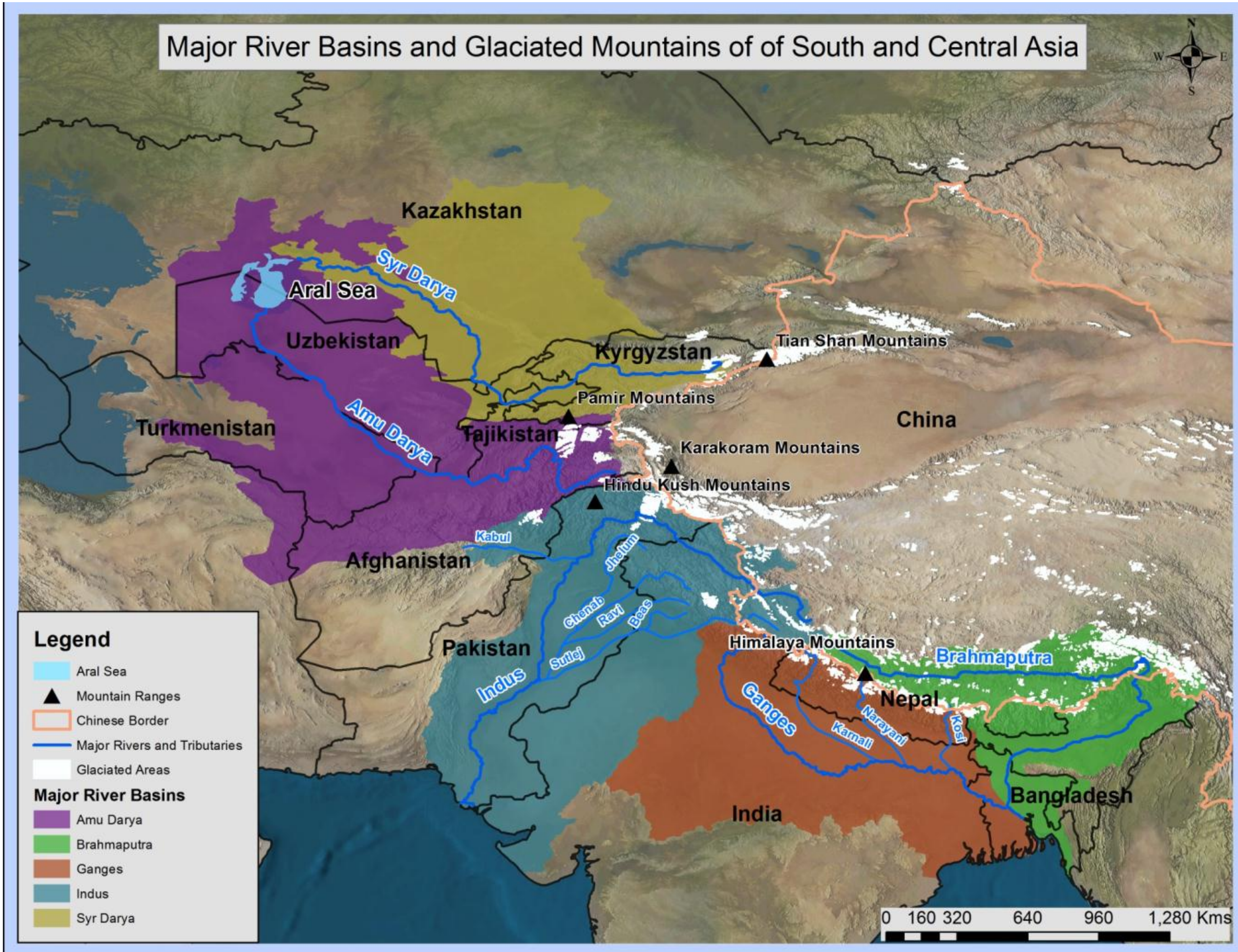
Conclusions

- River runoff dominated by summer monsoon in the eastern Himalaya – snow/ice plays minor role.
- Snow and glacier ice melt are major contributors to the water resources of the western Himalaya, Karakoram, Hindu Kush.
- Snow and glacier cover in the west appears to be reasonable stable over the past decade.
- Well-planned management, conservation, and efficient use of water currently available – as important as any changes that may take place in the regional climate in the near future.
- Need remains for accurate estimates of potential impact of reduced glacier melt contribution to downstream water resources in a warming climate.

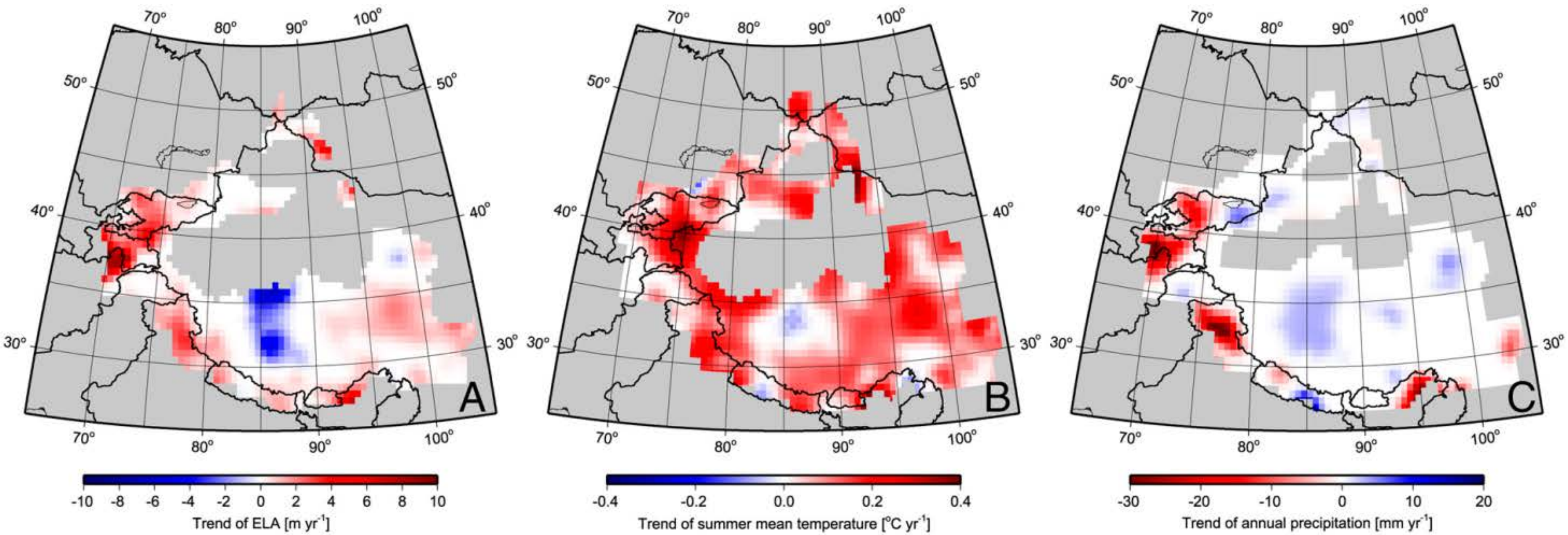
Acknowledgements

Richard Armstrong, CIRES/NSIDC, University of Colorado
Adina Racoviteanu, INSTAAR, University of Colorado
Mark Williams, INSTAAR, University of Colorado
Siri Jodha Singh Khalsa, CIRES/NSIDC, University of Colorado
Donald Alford, Consulting Hydrologist, Billings, Montana
James Wescoat, MIT, Cambridge, MA
Al Rasmussen, University of Washington, Seattle

Project Funding from World Bank, NASA , USAID



Major River Basins and Glaciated Mountains of of South and Central Asia
N
W
E
S
Kazakhstan
Aral Sea
Syr Darya
Uzbekistan
Kyrgyzstan
Tian Shan Mountains
Pamir Mountains
Turkmenistan
Amu Darya
Tajikistan
China
Karakoram Mountains
Hindu Kush Mountains
Kabul
Jhelum
Afghanistan
Chenab
Ravi
Beas
Pakistan
Sutlej
Indus
Himalaya Mountains
Brahmaputra
Nepal
Ganges
Karnali
Narayani
Kosi
Bangladesh
India
Legend
Aral Sea
Mountain Ranges
Chinese Border
Major Rivers and Tributaries
Glaciated Areas
Major River Basins
Amu Darya
Brahmaputra
Ganges
Indus
Syr Darya
0 160 320 640 960 1,280 Kms



Spatial distribution of the trends in ELA (A), summer mean temperature (B), and annual precipitation (C) for the period 1988–2007. Fujita and Nuimura, PNAS, 2011