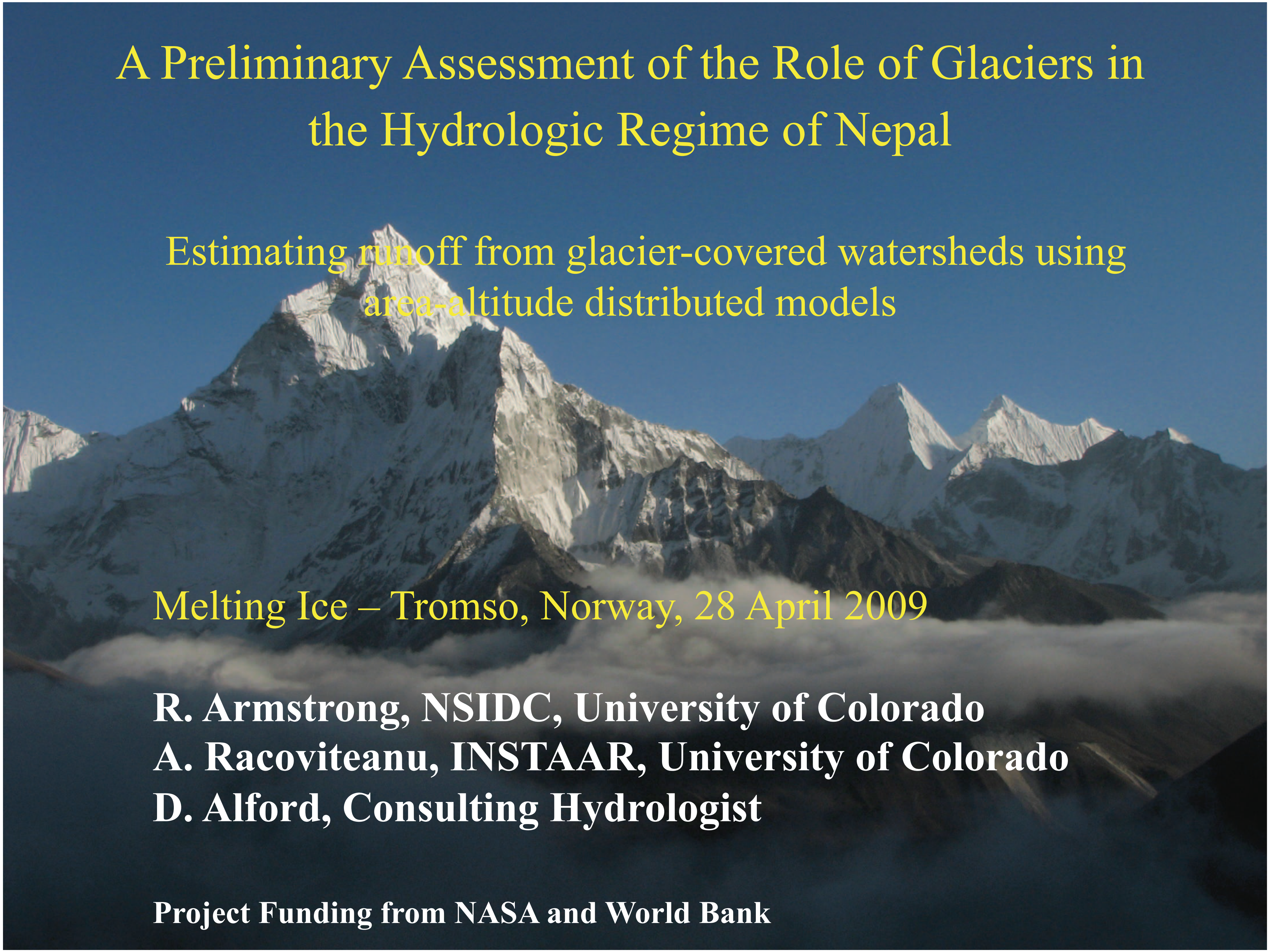


A Preliminary Assessment of the Role of Glaciers in the Hydrologic Regime of Nepal

Estimating runoff from glacier-covered watersheds using area-altitude distributed models

Melting Ice – Tromso, Norway, 28 April 2009

R. Armstrong, NSIDC, University of Colorado
A. Racoviteanu, INSTAAR, University of Colorado
D. Alford, Consulting Hydrologist

Project Funding from NASA and World Bank

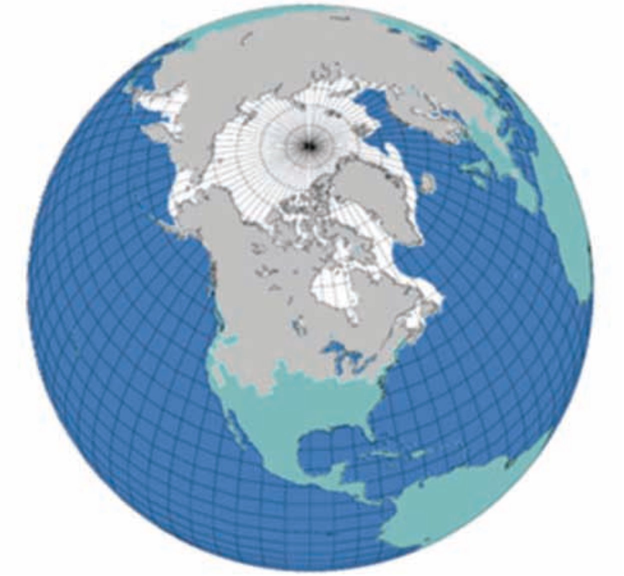
Outline

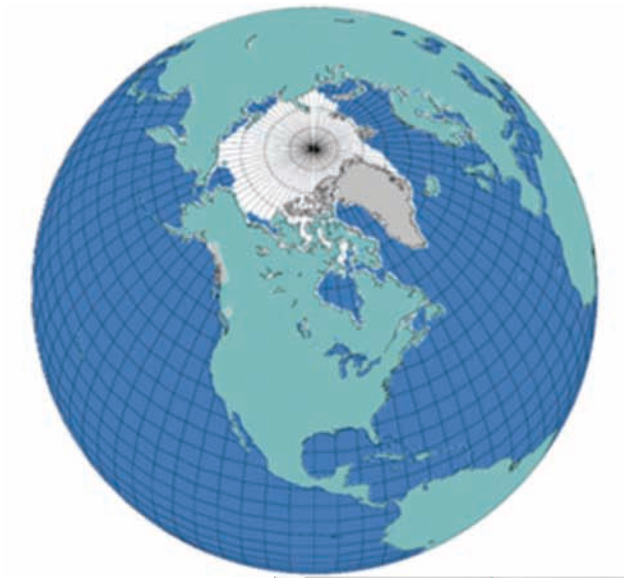
- Glacier Measurements and Misconceptions
- Introduction to Nepal/Himalayan Glaciers
  - Large elevation range
  - Few direct measurements
- Available Data to Characterize the Region
- Methods to Assess Current Status of Glaciers
- Results and Future Work

Northern Hemisphere Sea Ice and Snow Cover Area

> 40-year record of Inter-annual variability

Mean maximum





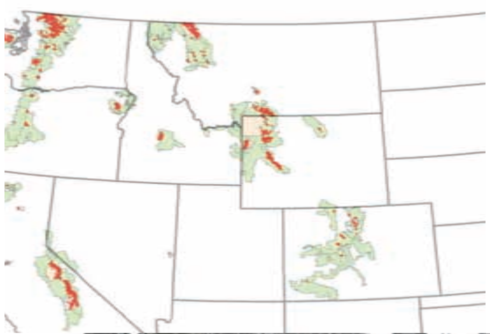
Mean minimum

Unlike sea ice, snow cover has no consolidated <u>minimum</u> to monitor – for residual seasonal snow, the targets are small and scattered: the snow remaining above the ELA within the accumulation zone of individual glaciers throughout the world, ~ 150,000.

Opportunity to Contrast Little Ice Age Climate Conditions with the Present in Locations such as the European Alps and North America.

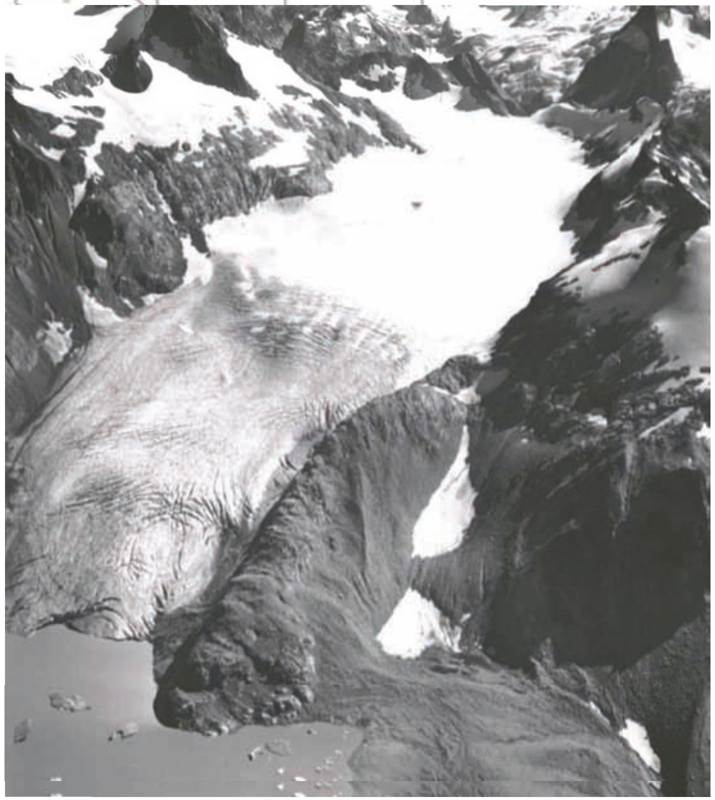
An 1870 postcard view of the Rhone glacier in Gletsch, Switzerland, contrasted with the shrinking 21st-century version of it. (Dominic Buettner for The New York Times)

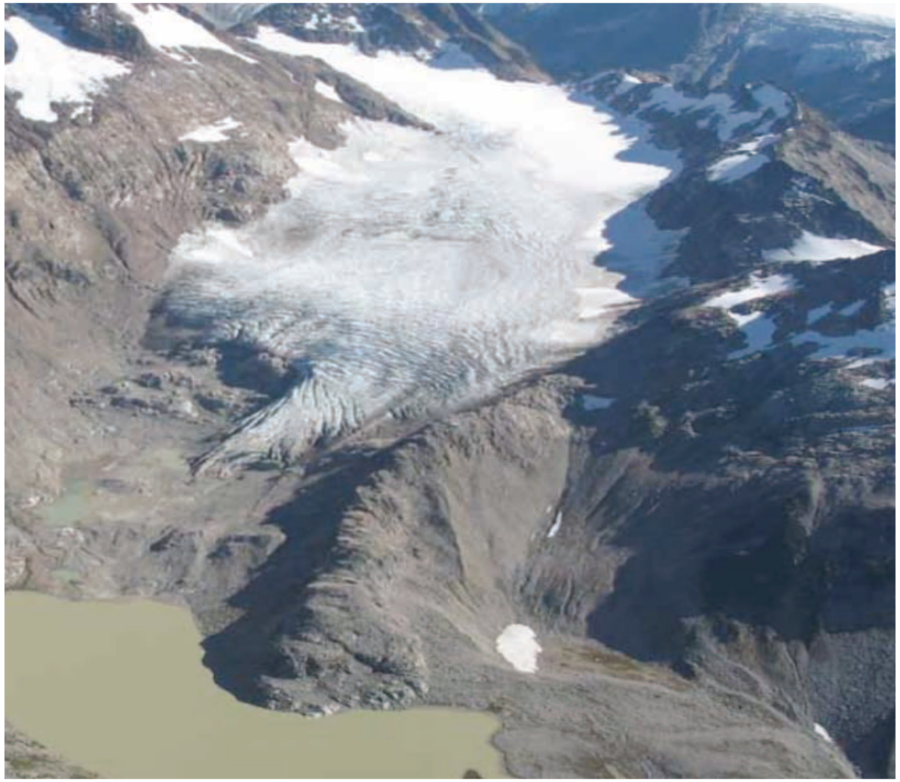
Location of Glaciers in CONUS



Fraction of Glacier Area Lost Western United States
Average ~40% since 1900.
Are such numbers representative
of other locations in the world?

Data from A. Fountain
Portland State University

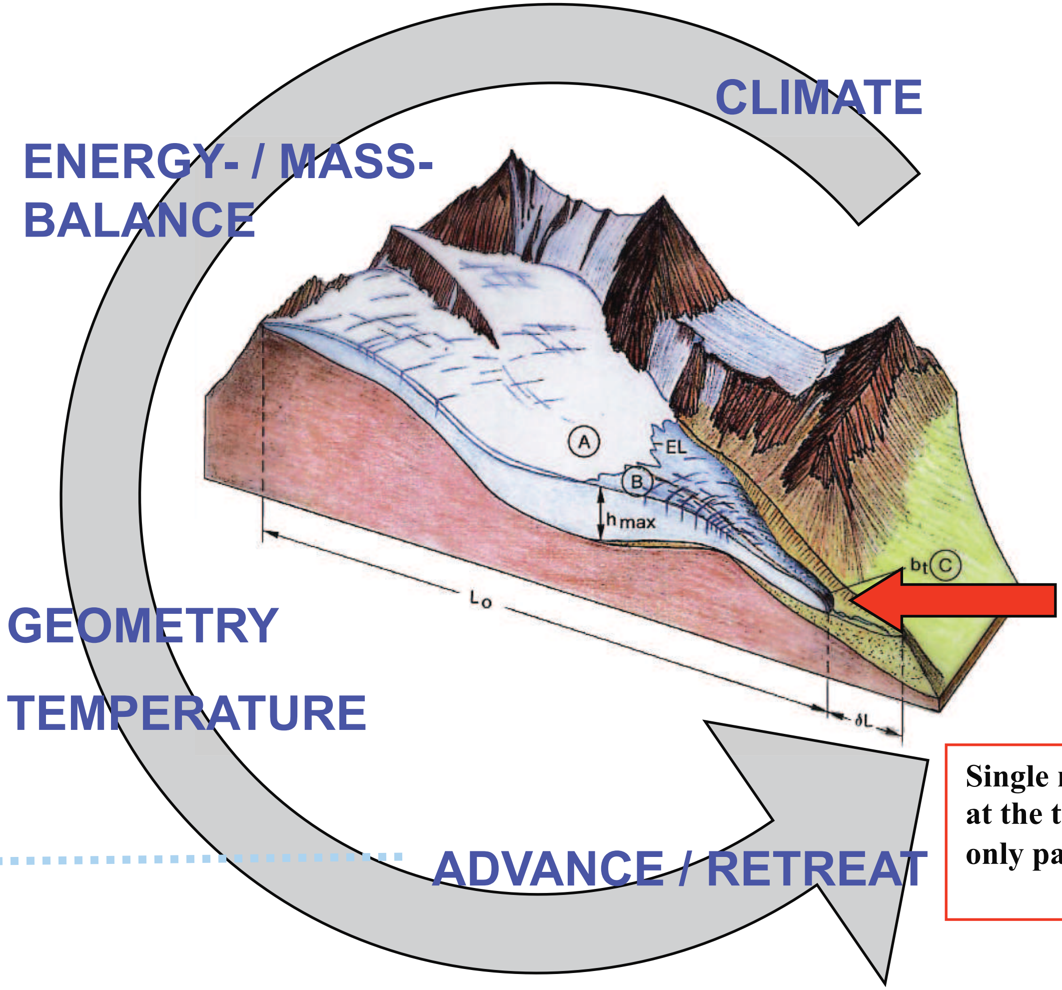




1960 South Cascade Glacier, Washington 2004

Terminus location data, the source of much of the information defining glacier status, are not always appropriate to describe the current health of total glacier systems.

Glacier crash course: climate-glacier process chain



direct, undelayed signal

indirect, delayed, filtered and enhanced signal

Single measurement at the terminus is only part of the story.

Haeberli (1998)

Fundamental characteristic of mountain regions, virtually all properties and processes vary with altitude. Himalayan region represents a very large range in altitude over a short distance, up to 7000 m.

Not representative of what is happening today at lower (warmer) altitudes.

Himalayan Range viewed from south-east to north-west

In the Himalaya: Some published reports promote misconceptions,

Glaciers are melting – (a normal seasonal process)

Glaciers are melting rapidly – (given a warming climate, true in many locations)

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)

There must be more to the “story” - a clear need to reduce un-certainty by bridging some of the more significant data gaps.

Glaciers in the Himalaya are receding faster than in any other part of the world (see Table 10.9) and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate. Its total area will likely shrink from the present 500,000 to 100,000 km² by the year 2035 (WWF, 2005).

High Mountain Asia	114 800 km²
Himalaya	33 050 km²
Karakoram	16 600 km²
Tien Shan	15 417 km²
Kunlun Shan	12 260 km²
Pamir	12 260 km²

Dyurgerov and Meier (2005)

Record Retreat?

Table 10.9. *Record of retreat of some glaciers in the Himalaya.*

Glacier	Period	Retreat of snout (metre)	Average retreat of glacier (metre/year)
Triloknath Glacier (Himachal Pradesh)	1969 to 1995	400	15.4
Pindari Glacier (Uttaranchal)	1845 to 1966	2,840	135.2
Milam Glacier (Uttaranchal)	1909 to 1984	990	13.2
Ponting Glacier (Uttaranchal)	1906 to 1957	262	5.1
Chota Shigri Glacier (Himachal Pradesh)	1986 to 1995	60	6.7
Bara Shigri Glacier (Himachal Pradesh)	1977 to 1995	650	36.1
Gangotri Glacier (Uttaranchal)	1977 to 1990	364	28.0
Gangotri Glacier (Uttaranchal)	1985 to 2001	368	23.0
Zemu Glacier (Sikkim)	1977 to 1984	194	27.7

WWF (World Wildlife Fund), 2005: An overview of glaciers, glacier retreat, and subsequent impacts in Nepal, India and China. World Wildlife Fund, Nepal Programme, 79 pp.

No comparison to other locations in the world - and are they even regionally representative?

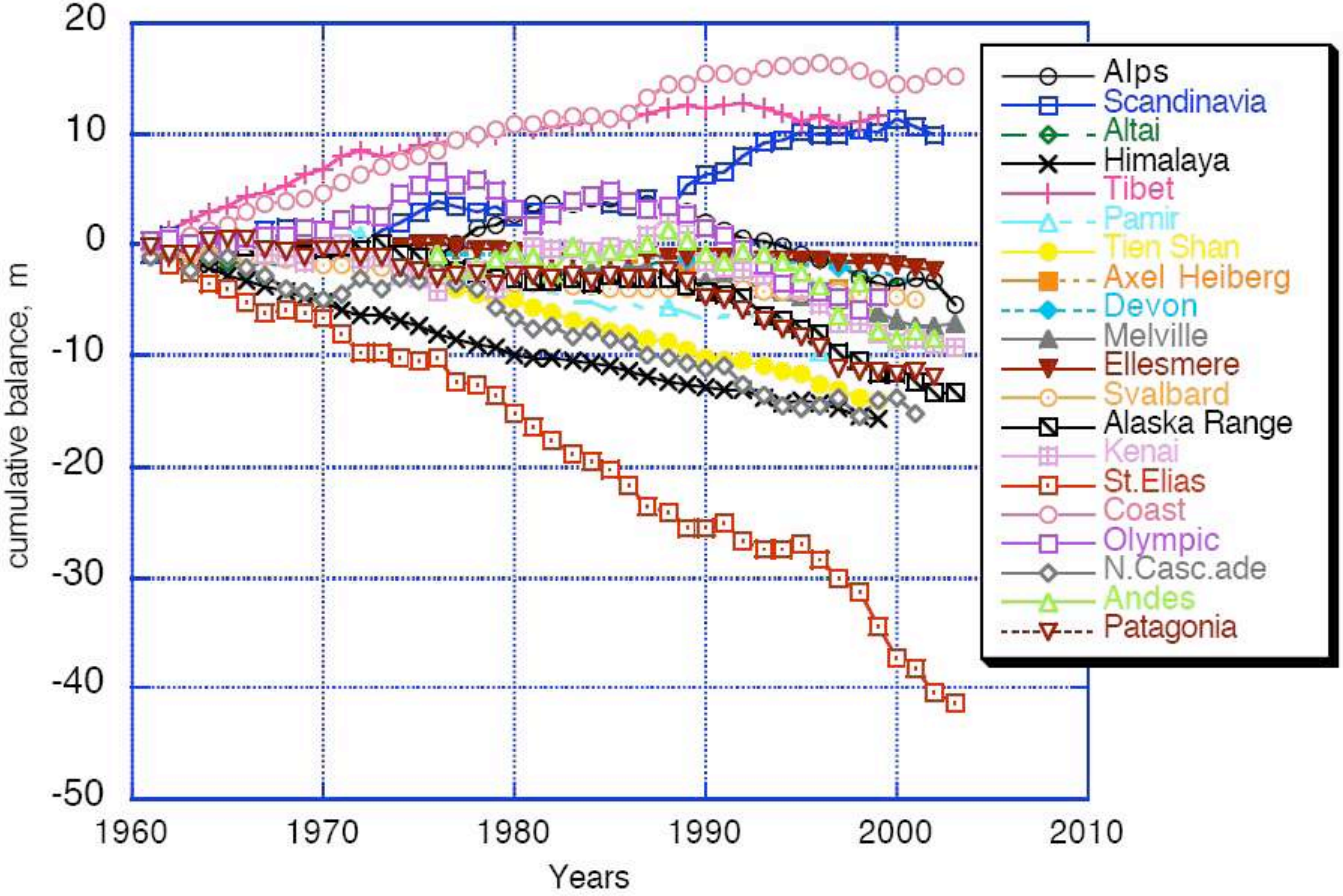
Glacier retreat around the world

TROPICS

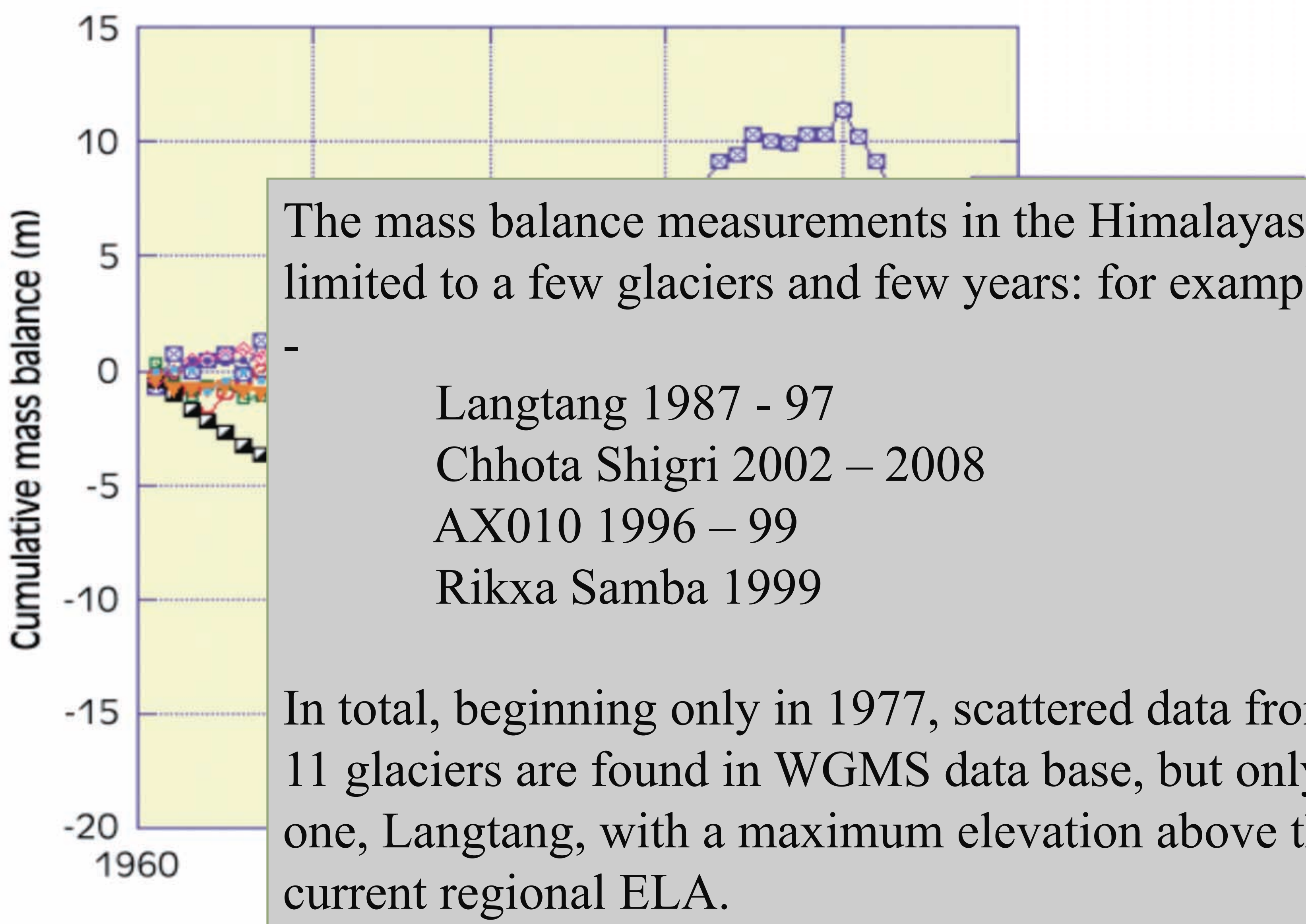
MID-LATITUDES

From: Racoviteanu et al, J of Glaciol, 2008

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



A different version of the same story: "The Melting Himalayas"



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

Langtang 1987 - 97
Chhota Shigri 2002 – 2008
AX010 1996 – 99
Rikxa Samba 1999

In total, beginning only in 1977, scattered data from 11 glaciers are found in WGMS data base, but only one, Langtang, with a maximum elevation above the current regional ELA.

General Research Questions

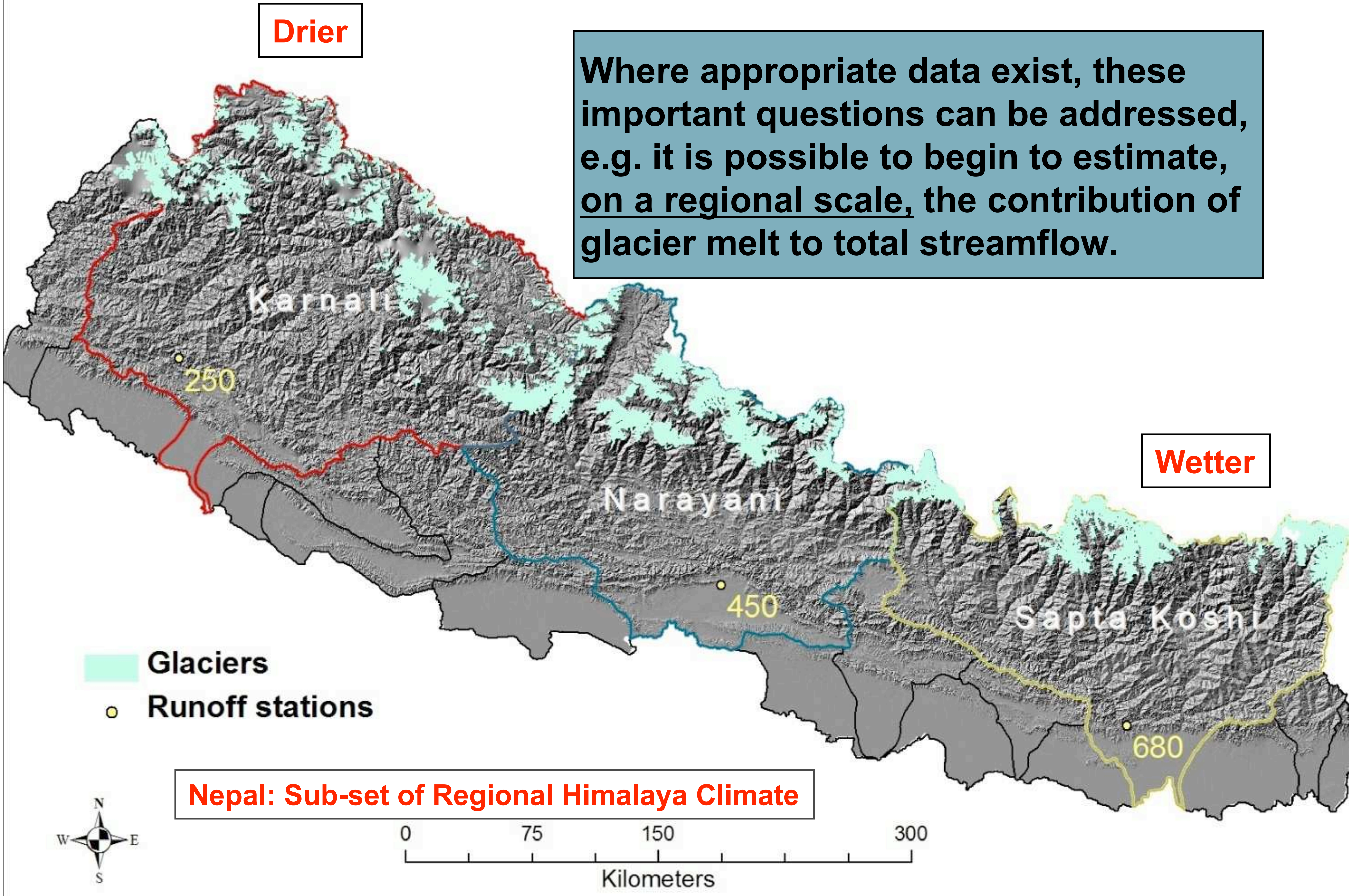
1) What is the current role of glaciers in the hydrologic regime of the Himalaya ?

2) What will be the impact of the retreat of Himalayan glaciers on future regional water supplies?

Specific purpose of this pilot study:

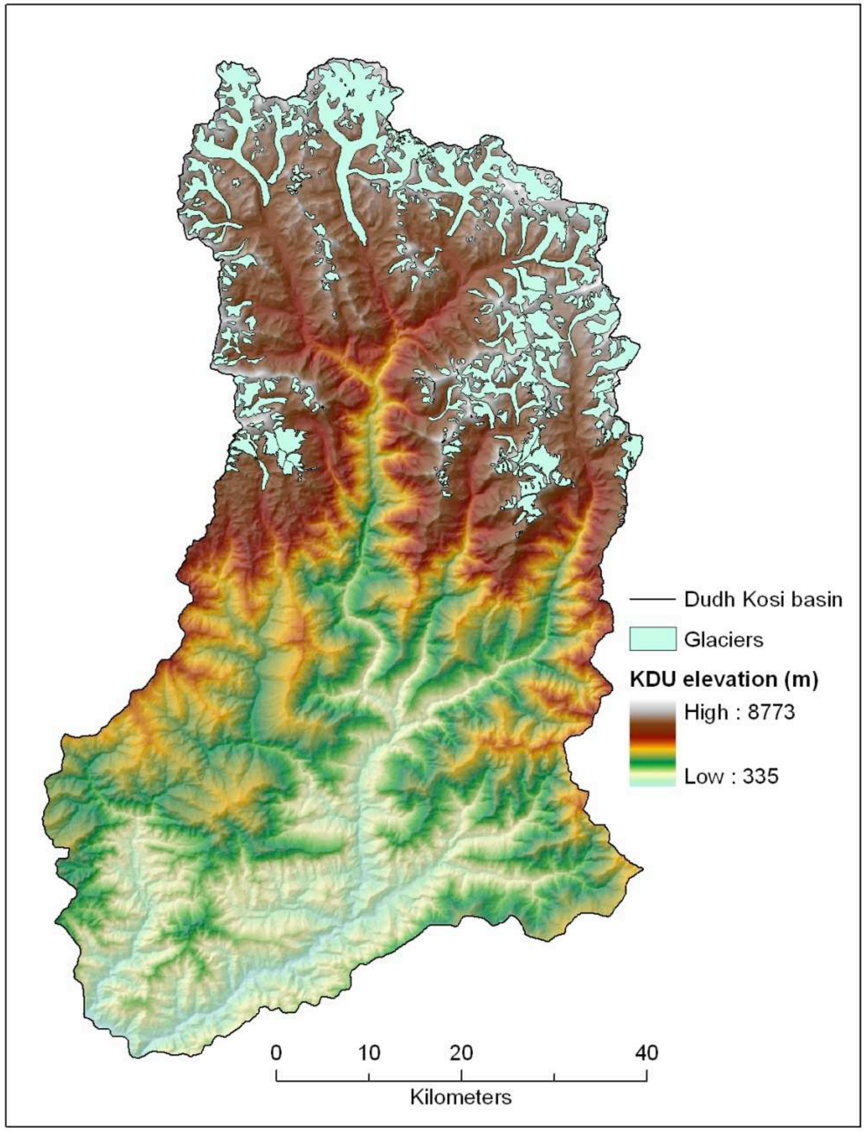
To develop and test simple, robust methodologies to quantify the role of glaciers in the hydrologic regime of Nepal at large spatial scales. Reduce uncertainty by applying actual data, limited as they might be.

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



Nepal: Sub-set of Regional Himalaya Climate

Data sources (GIS database)

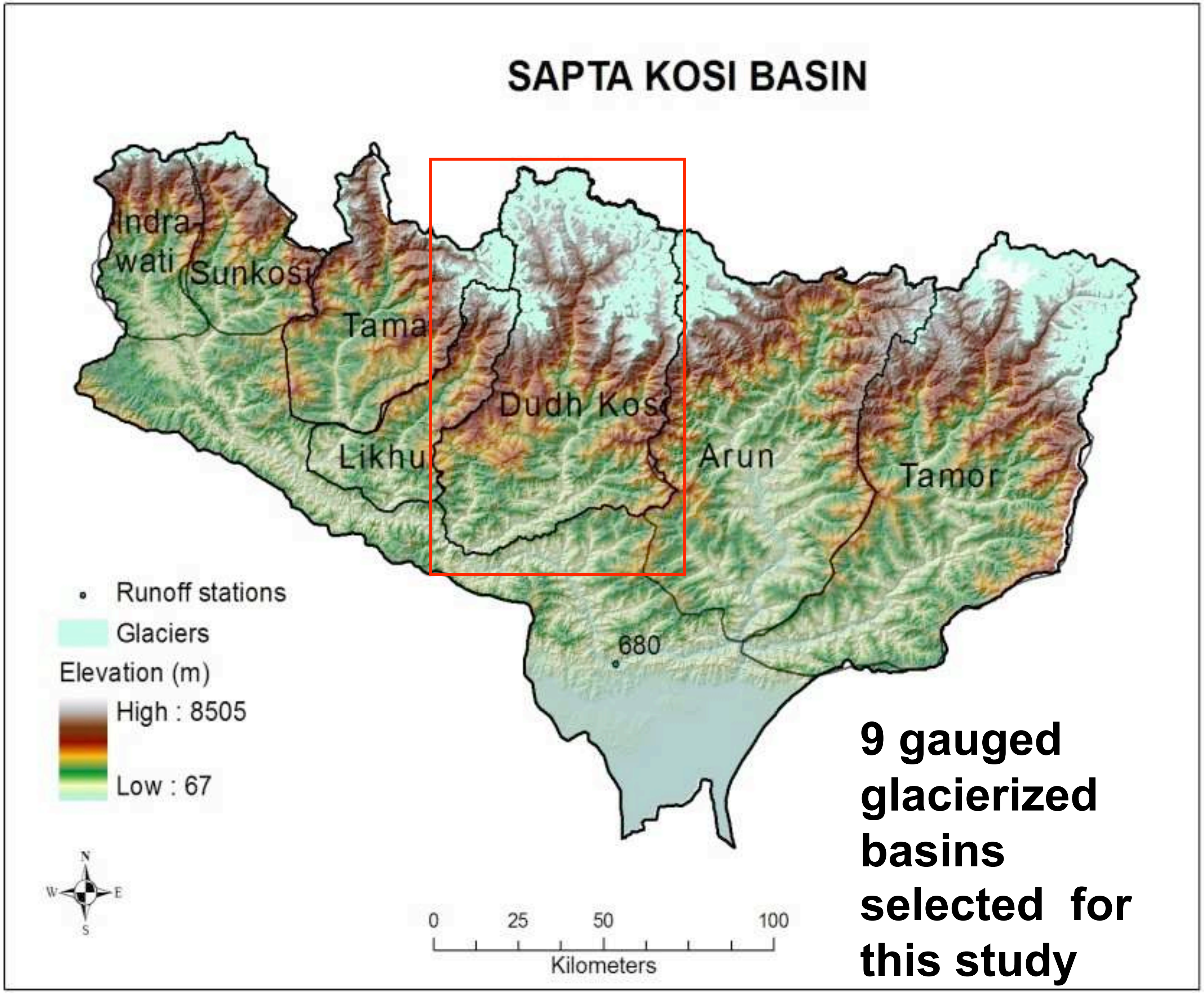


- Digital elevation model (DEM) from the 2000 Shuttle Radar Topography Mission (SRTM v.4) (90m spatial resolution).

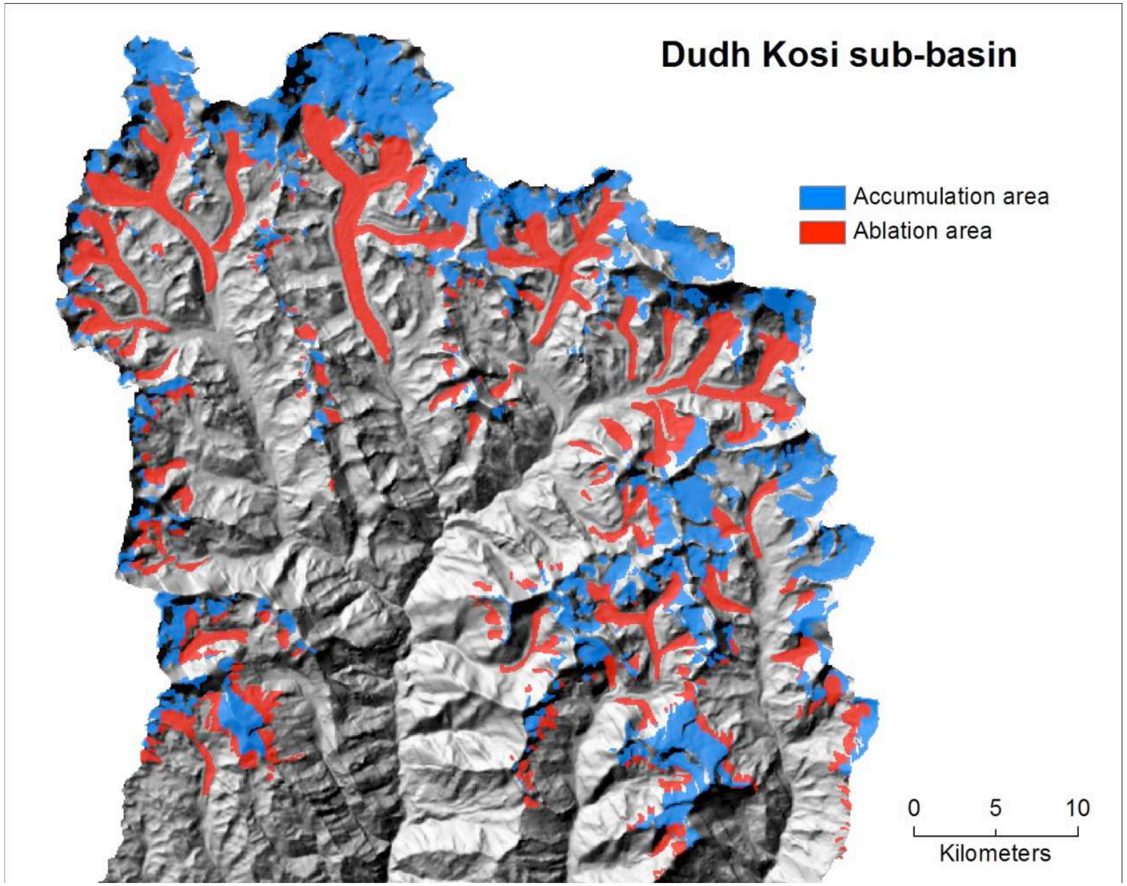
- Glacier outlines for Nepal from topographic maps (ICIMOD / GLIMS)

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

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


SAPTA KOSI BASIN
Indra-
wati
Sunkosi
Tama
Dudh Kosi
Likhu
Arun
Tamor
680
Runoff stations
Glaciers
Elevation (m)
High : 8505
Low : 67
N
W
E
S
0
25
50
100
Kilometers
9 gauged glacierized basins selected for this study

Define Accumulation and Ablation Areas
Area-Altitude Mass Balance Model

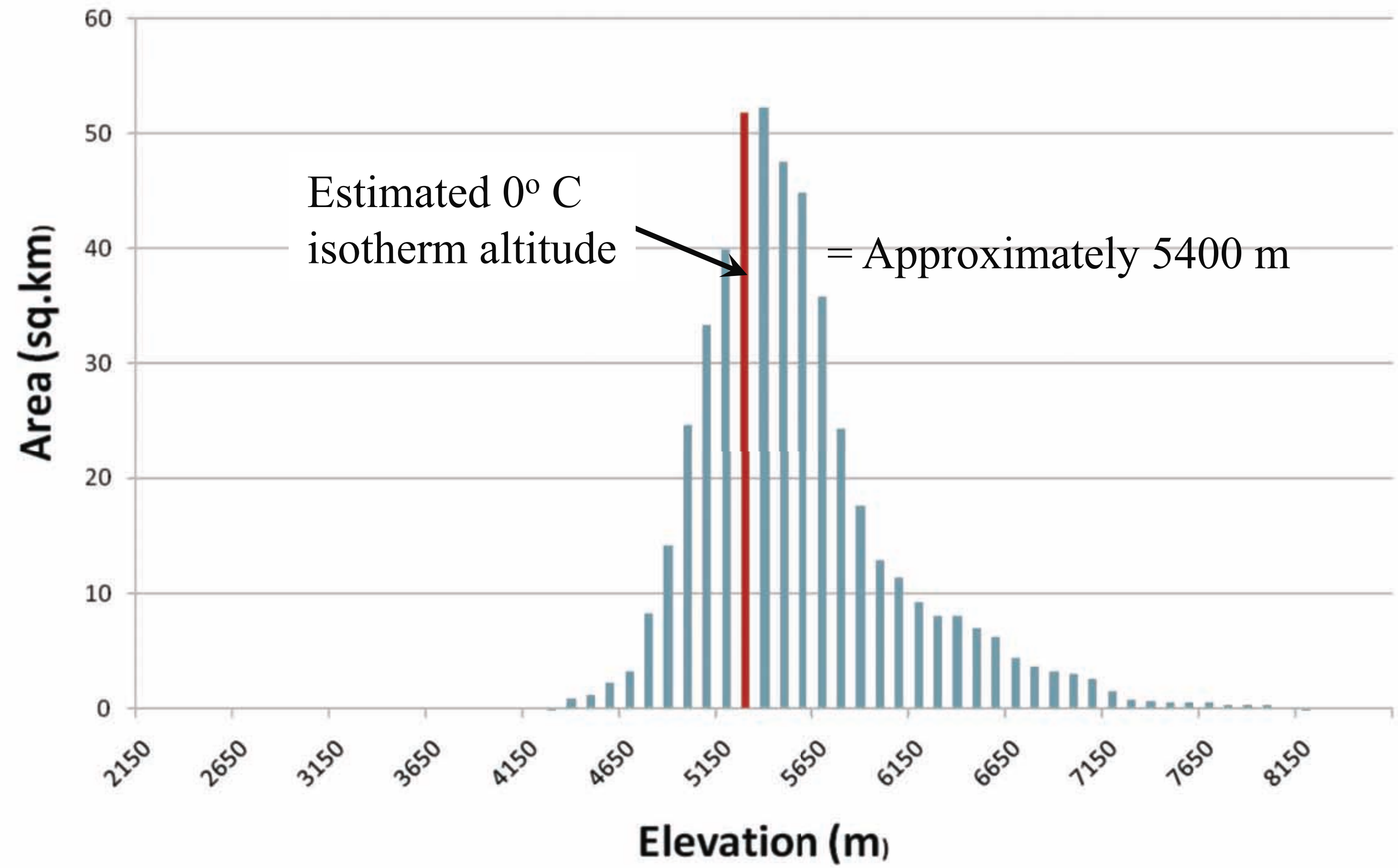


Let the regional 0 ° Isotherm represent the Equilibrium Line Altitude (ELA)

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

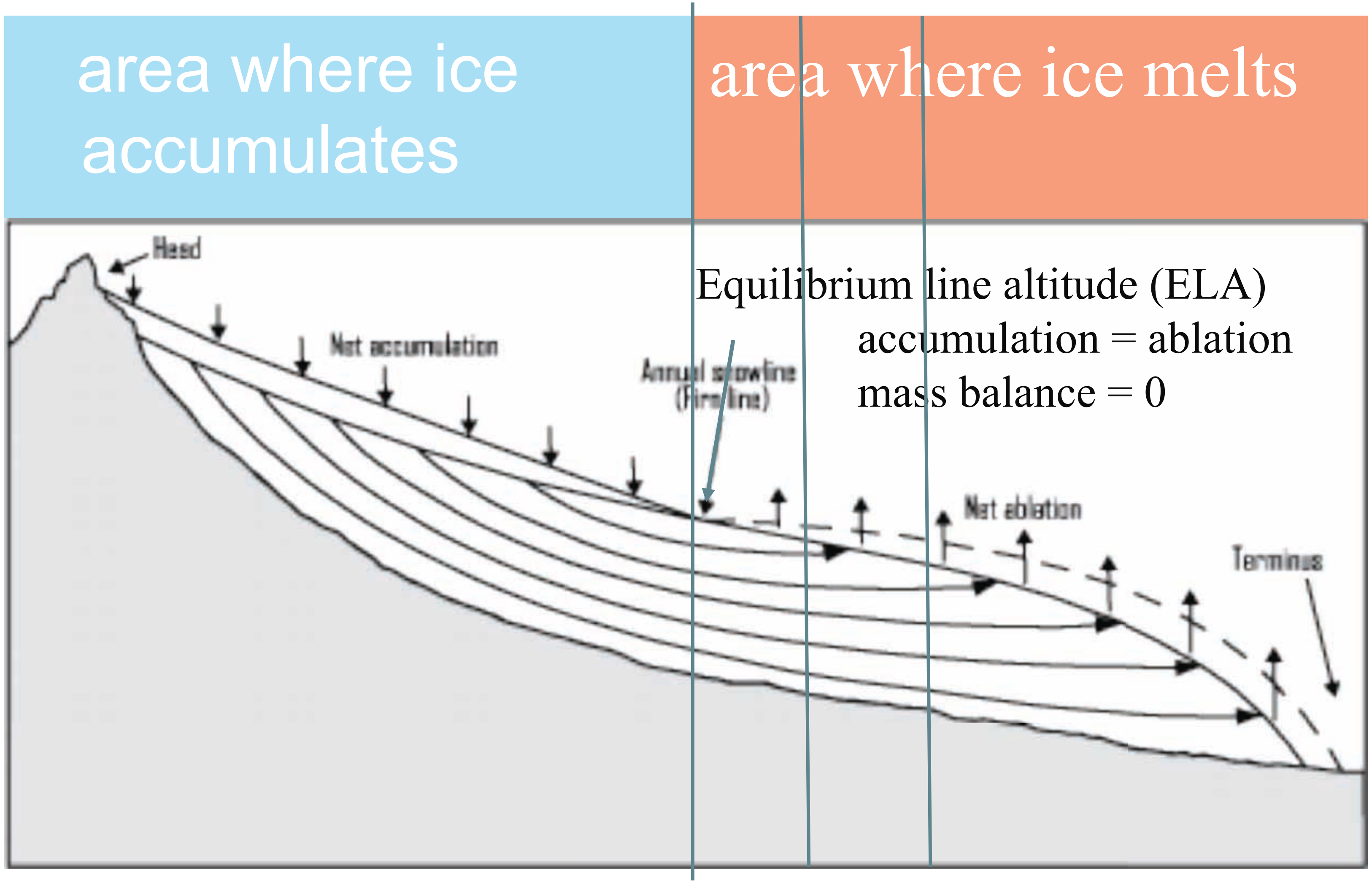
Hypsometry of glacier covered area of Dudh Kosi



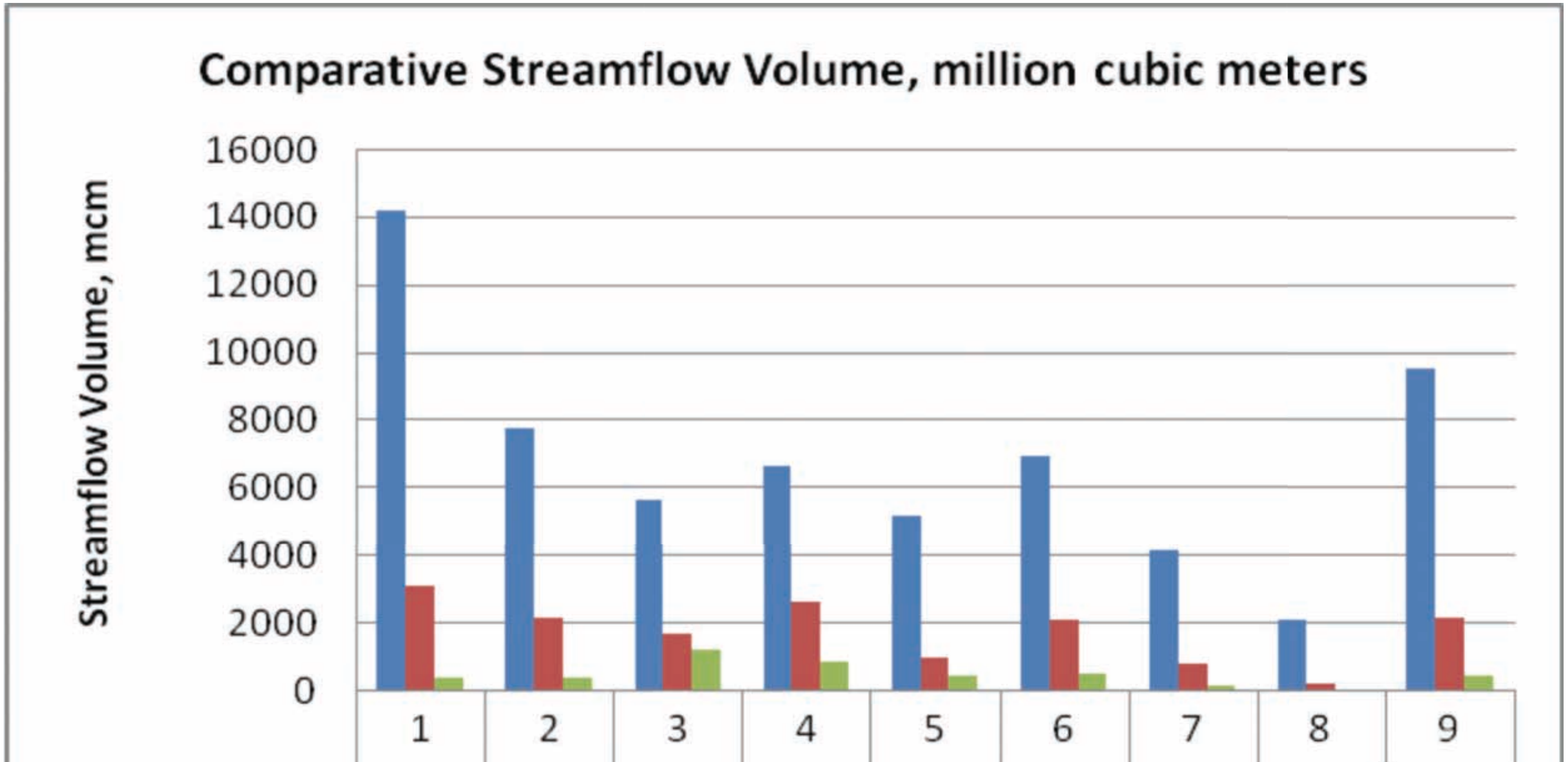
Compute melt below this altitude using:
1) regional mass balance gradient, or
2) positive degree data methods.

Runoff from melting ice -

0 1.4m 2.8m….



5400 5300 5200 ……



	1	2	3	4	5	6	7	8	9
Basin	14149	7765	5624	6672	5192	6929	4153	2091	9510
4-6 K m	3118	2197	1682	2669	1007	2130	828	247	2194
Glacier Melt	418	421	1248	878	482	496	160	52	484

Histogram, showing preliminary estimates of relative streamflow, in million cubic meters, mcm, for basin totals, the 4000-6000 m altitudinal belt, and glacier melt, for 9 gauged basins in the Nepal Himalaya. Catchment Basins are: 1. Bheri, 2. Kali Gandaki, 3. Budhi Gandaki, 4. Marsyangdi, 5. Trisuli, 6. Dudh Kosi, 7. Tama Kosi, 8, Likkhu, 9 Tamor.

Summary of Preliminary Results

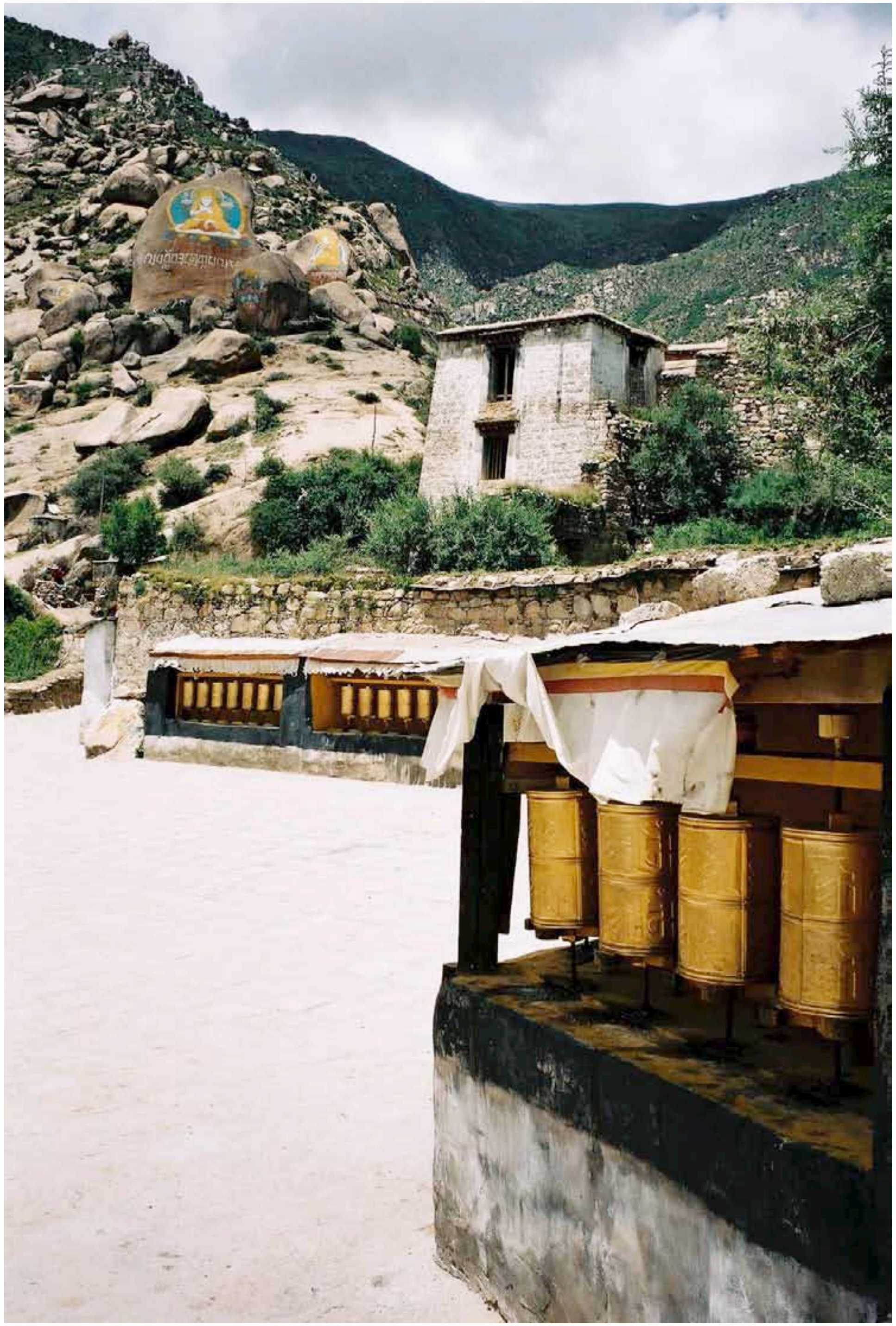
- The annual contribution of glacier melt water to annual streamflow volume varies among the 9 catchment basins from approximately 2-13%.

- This glacier melt contribution is estimated to be about 2-3% of the total annual streamflow volume of the rivers of Nepal.

Future Work

- Refine model estimates using additional input data, more published results and new field data.
- Continue to focus on measurements that characterize a region and not only a few single points.
- Run melt models with an increasing 0 deg. isotherm altitude, corresponding to a warming climate.

THANK YOU ---



Importance of Himalayan glaciers

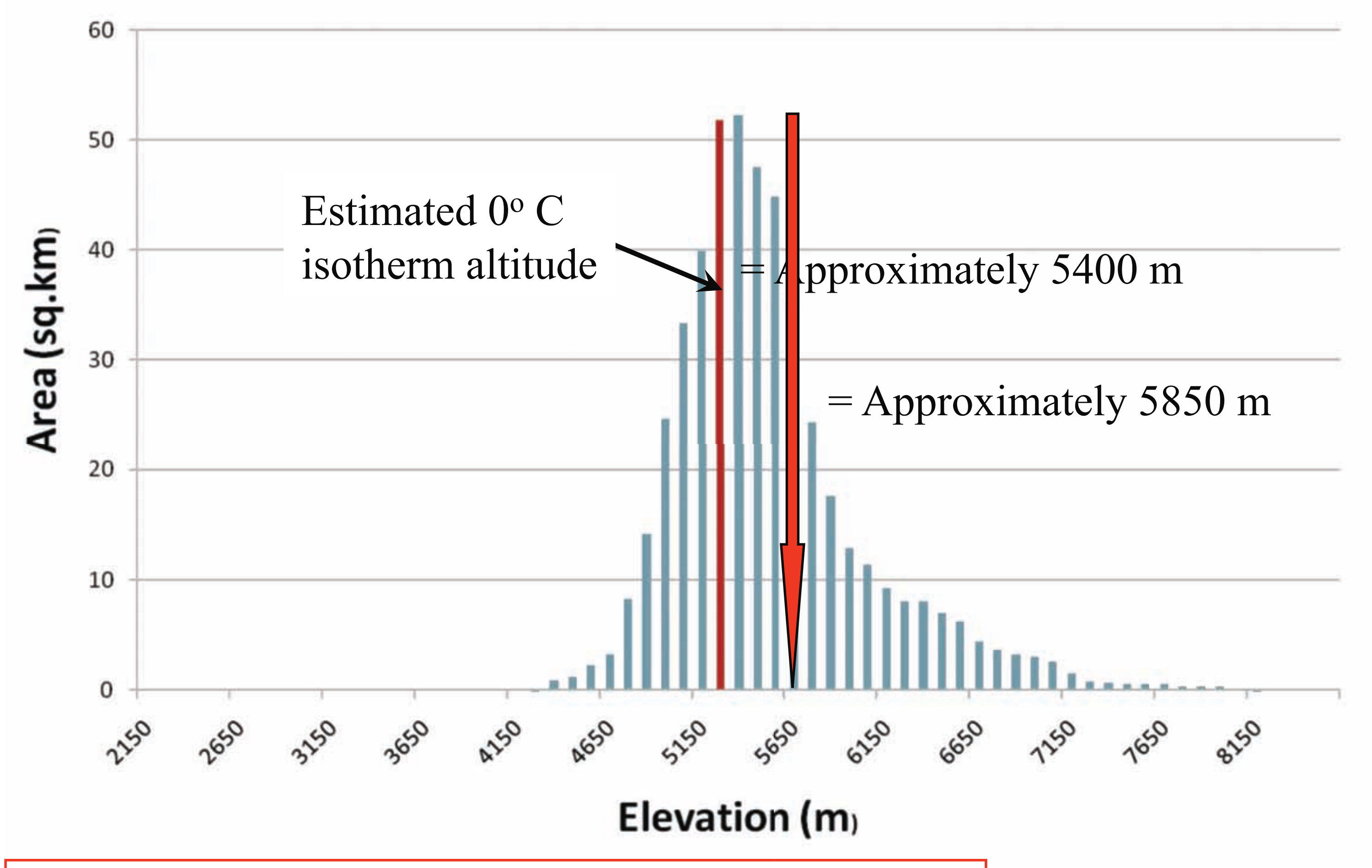
Continental Scale:

- hydrologic cycle
- radiation balance
- atmospheric circulation

Regional/Local Scale:

- water for irrigation, domestic, hydropower generation
- glacier hazards (glacier surges, GLOFs)
- religious importance (sacred mountains)

Hypsometry of glacier covered area of Dudh Kosi



Compute melt below this altitude using:

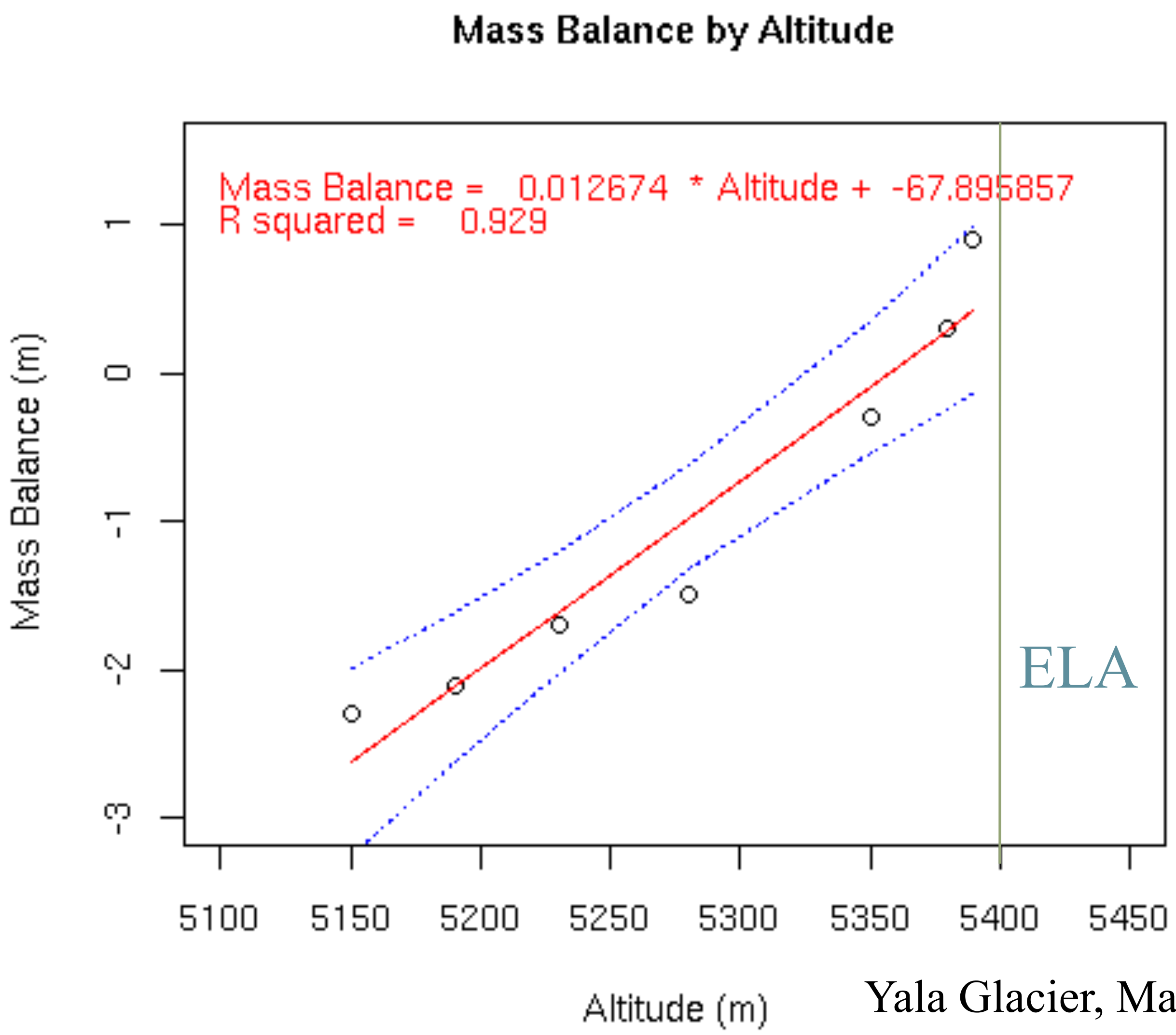
1) regional mass balance gradient, or

2) positive degree data methods.

Work in progress

- Refine db/dz using additional field measurements
- Compare db/dz model with degree-day model estimates of melt
- Estimate ELA from remote sensing
- Estimate melt rates under debris cover
- Investigate seasonality of runoff – low flow
- Run melt models with an increasing 0 deg. isotherm altitude corresponding to a warming climate

Mass Balance Gradient: Yala Glacier



db/dz = The mass balance profile within a given climatic region and period remains approximately independent of the yearly fluctuations of the ELA.

Yala Glacier, May-October 1996 (Fujita et al. 1998). Reproduced from Konz et al. 2006.

Mass Balance Gradient: approximately independent of annual fluctuations of mass balance: Example from Blue Glacier, Washington, USA

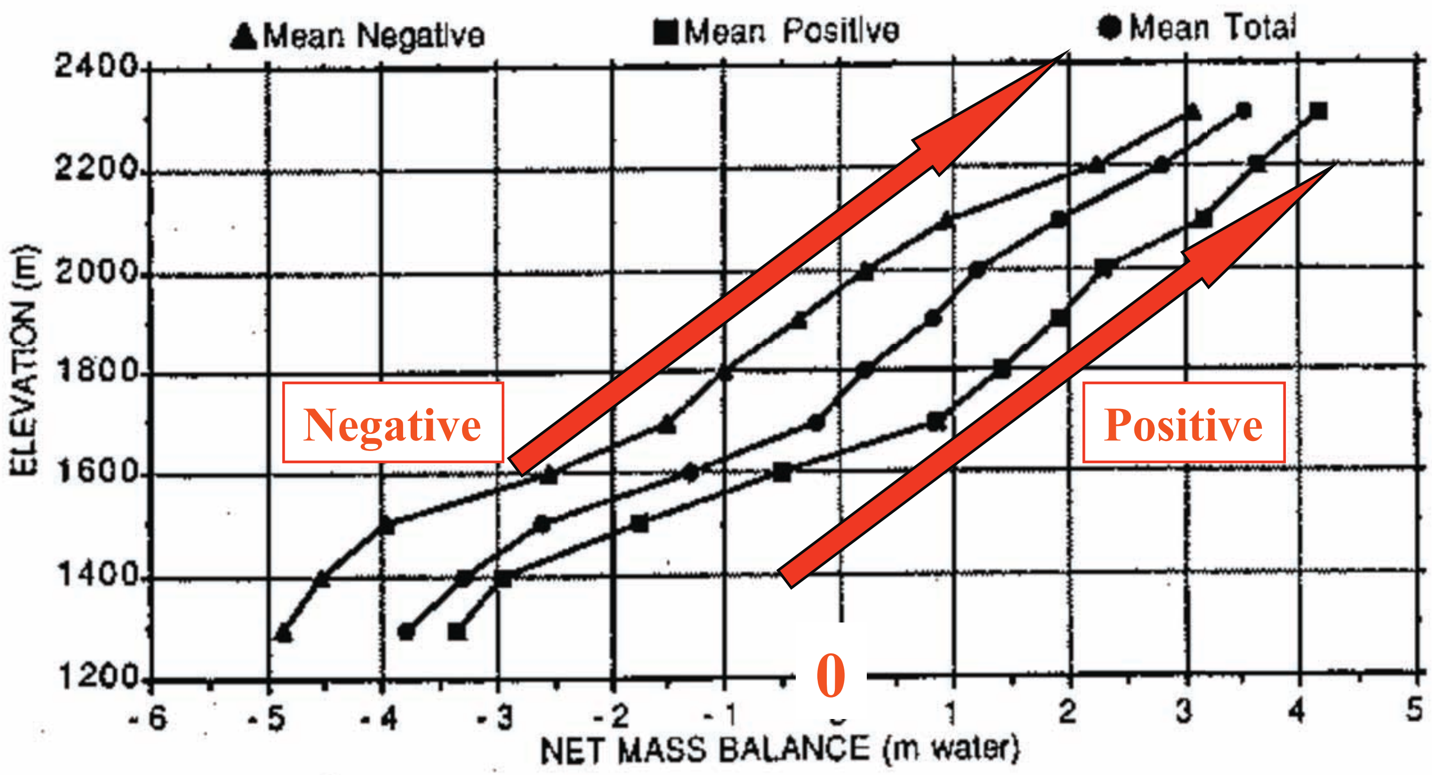


Figure 11. Average mass balance as a function of elevation for the five most negative years, the five most positive years, and the average for the total period of record for Blue Glacier.

Armstrong (1989) in: Glacier Fluctuations and Climate Change. J. Oerlemans Ed..

Nepal Himalayas

- Glacier AX010 of Shorong Yul-lha (Numbur) estimated to disappear by 2060

- Mass balance measurements in 1979; 1996 – 1999

Altitude: 4950- 5360m

(a)

(b)

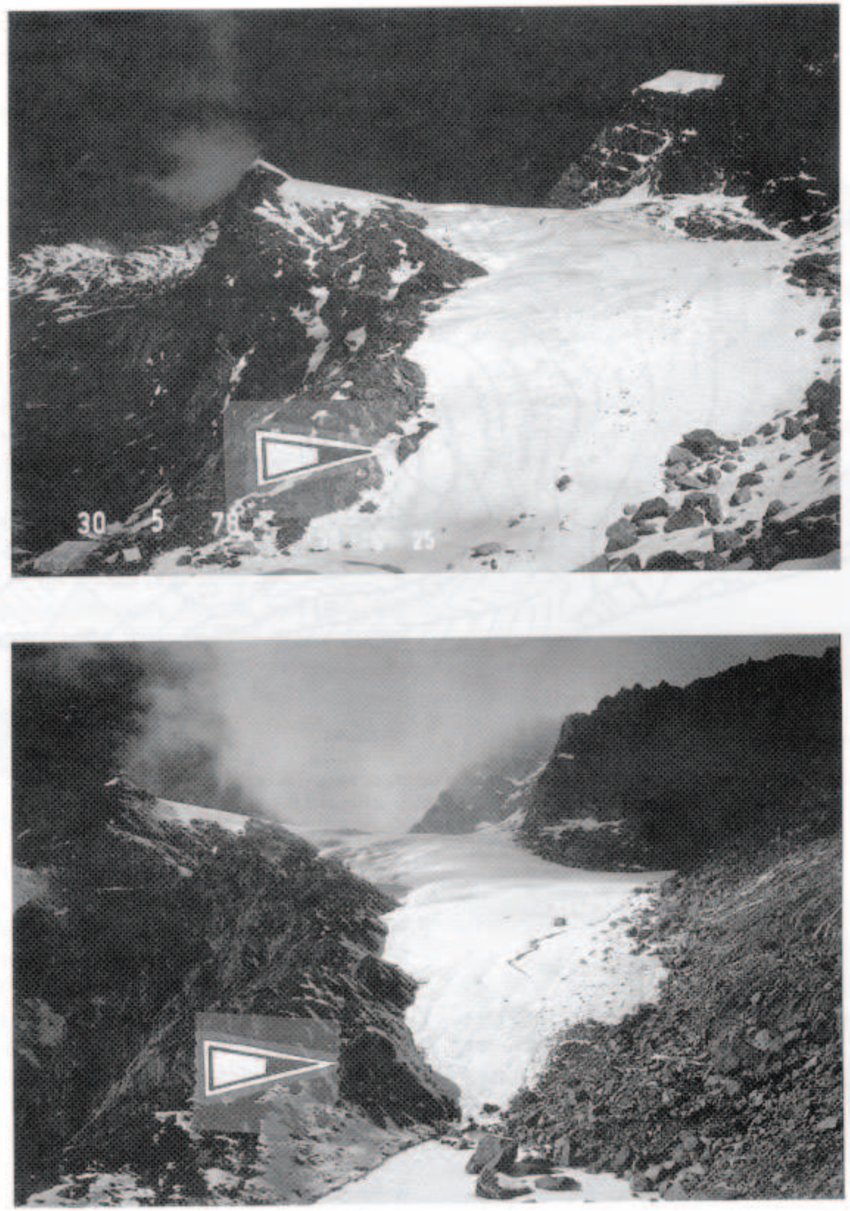


Fig. 4. Photographs of the lower part of Glacier AX010 taken in June 1978 (a), and in November 1989 (b). Shrinkage of the glacier is evident as shown by arrows in (a) and (b) at the same point.