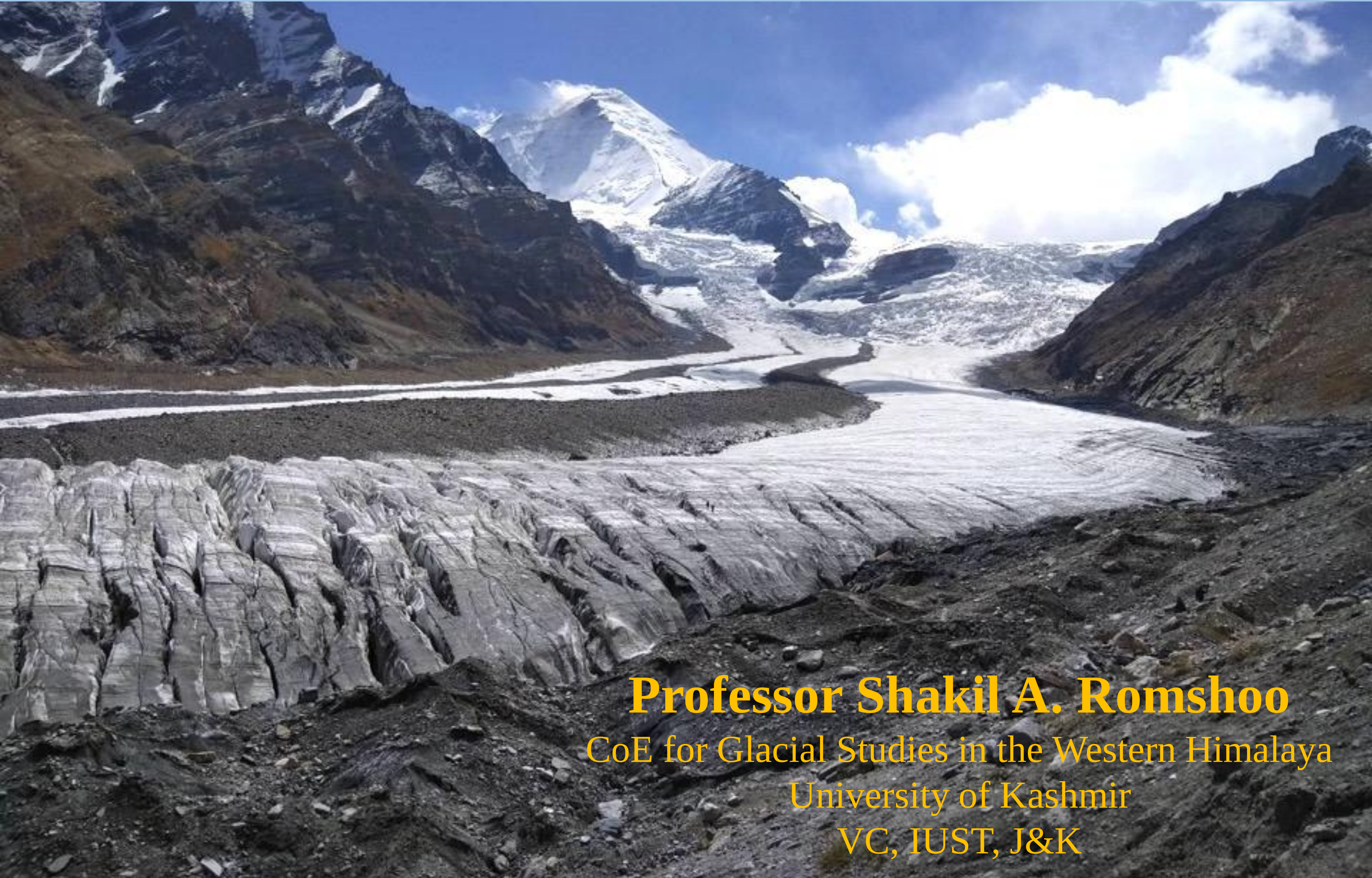
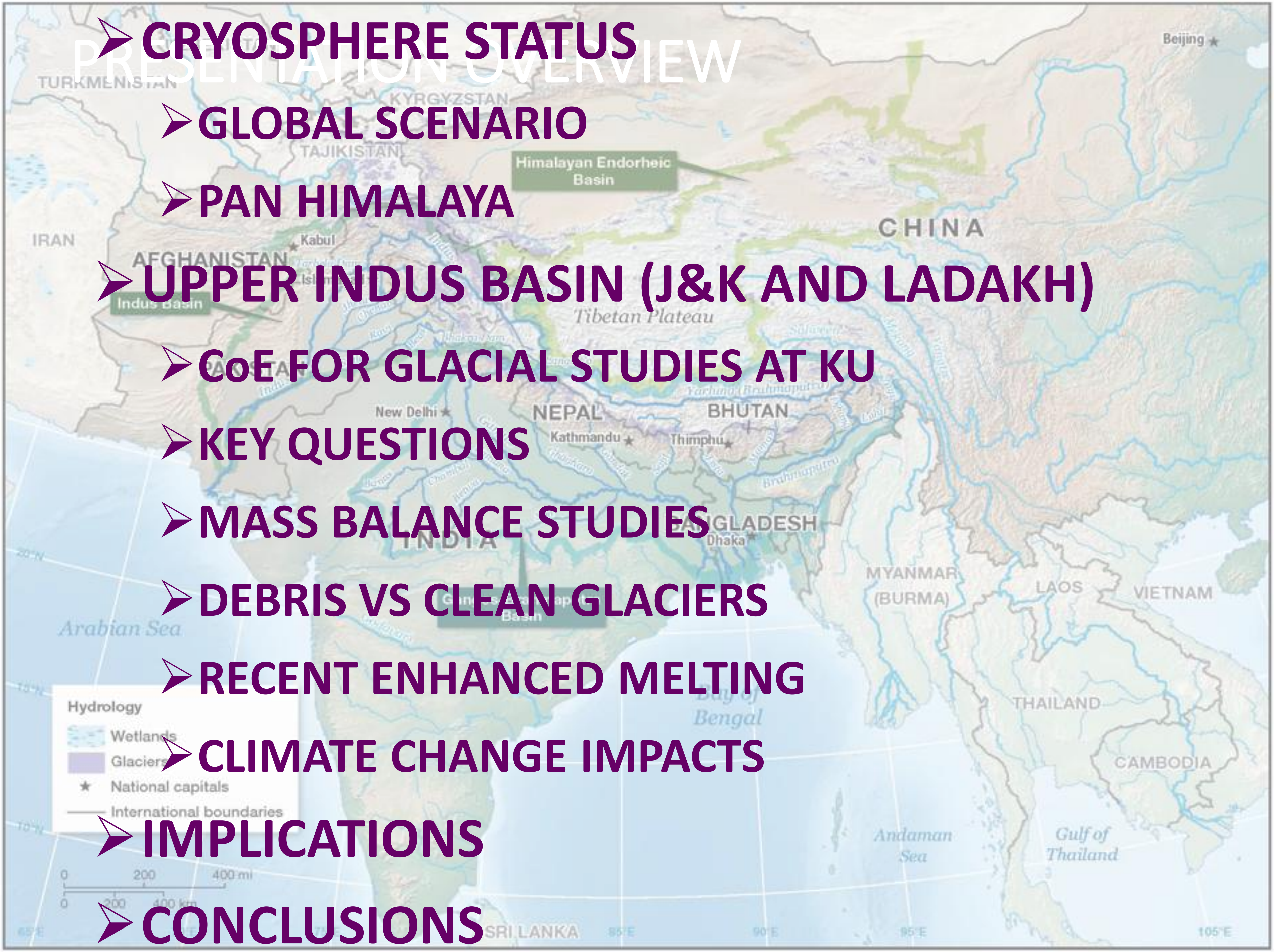
MELTING CRYOSPHERE IN NW HIMALAYA, FUTURE PROJECTIONS AND IMPLICATIONS



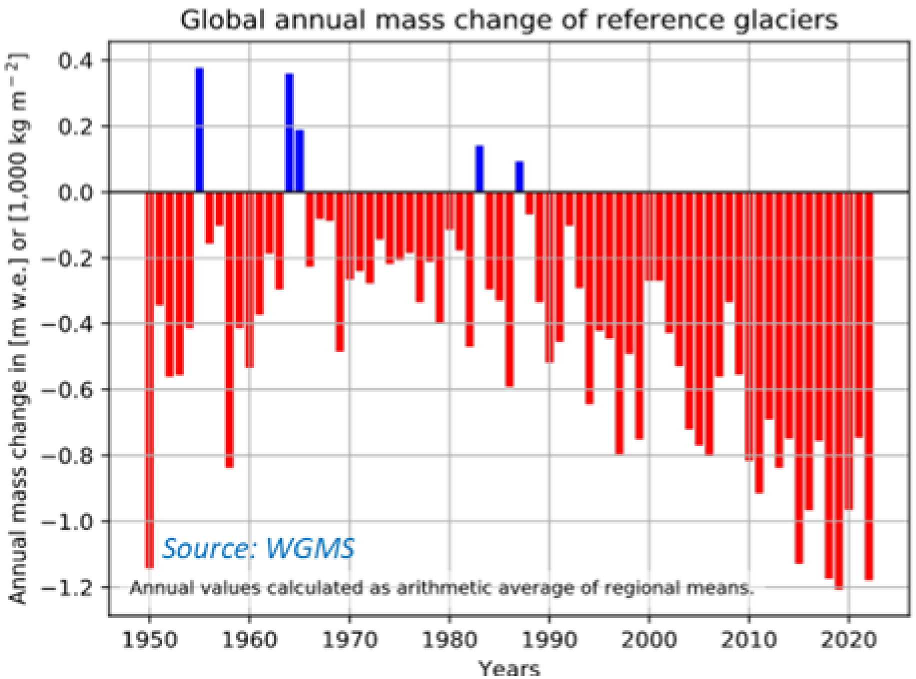
Professor Shakil A. Romshoo
CoE for Glacial Studies in the Western Himalaya
University of Kashmir
VC, IUST, J&K

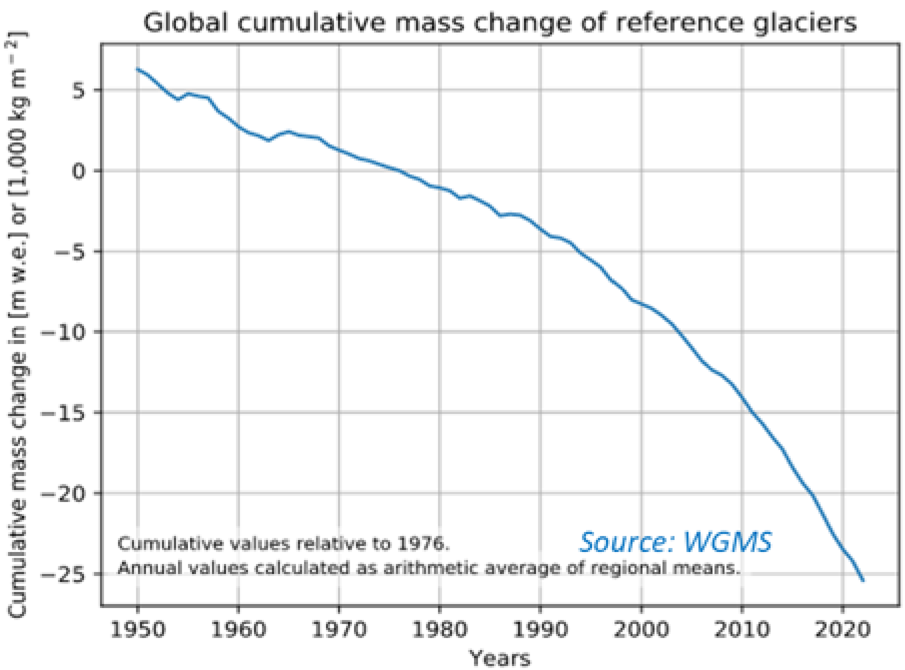
PRESENTATION OVERVIEW

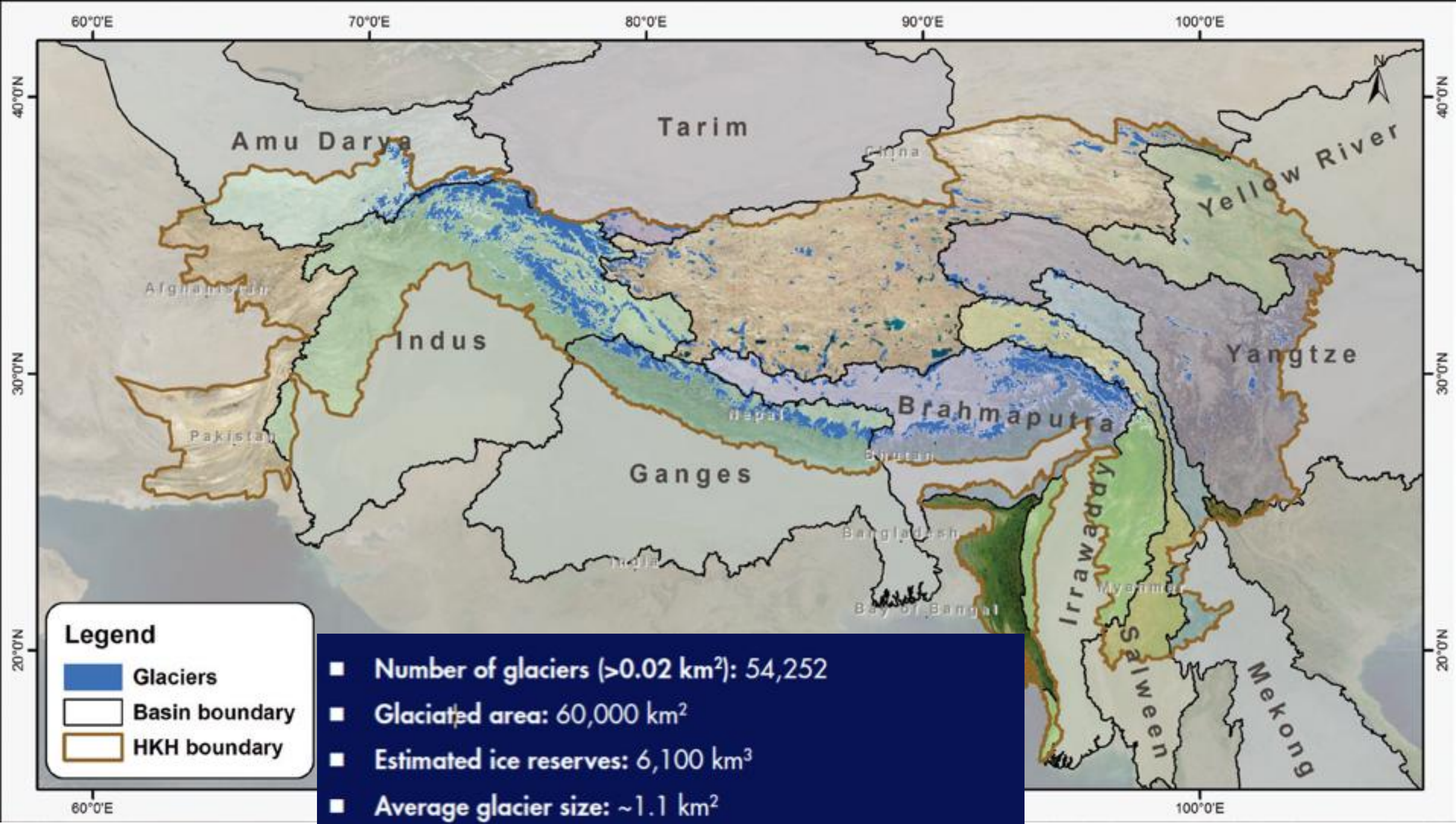
- CRYOSPHERE STATUS
  - GLOBAL SCENARIO
  - PAN HIMALAYA
- UPPER INDUS BASIN (J&K AND LADAKH)
  - CoE FOR GLACIAL STUDIES AT KU
  - KEY QUESTIONS
  - MASS BALANCE STUDIES
  - DEBRIS VS CLEAN GLACIERS
  - RECENT ENHANCED MELTING
  - CLIMATE CHANGE IMPACTS
- IMPLICATIONS
- CONCLUSIONS



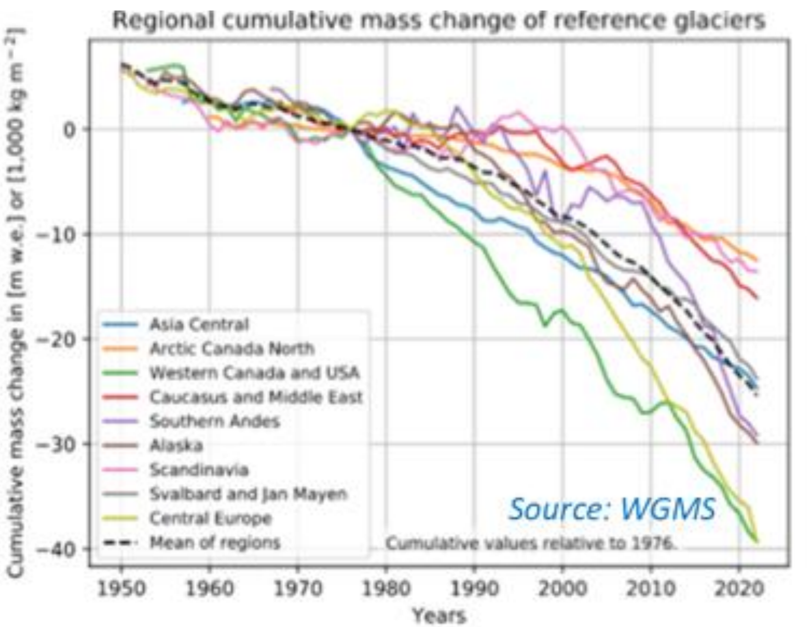
HOW ARE OUR GLACIERS DOING?

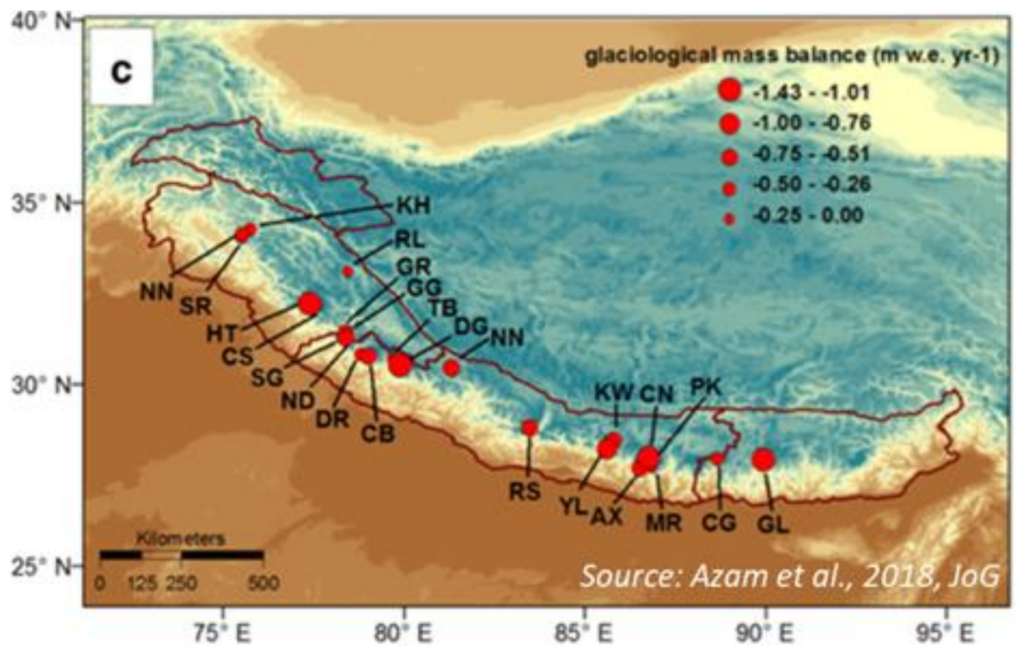


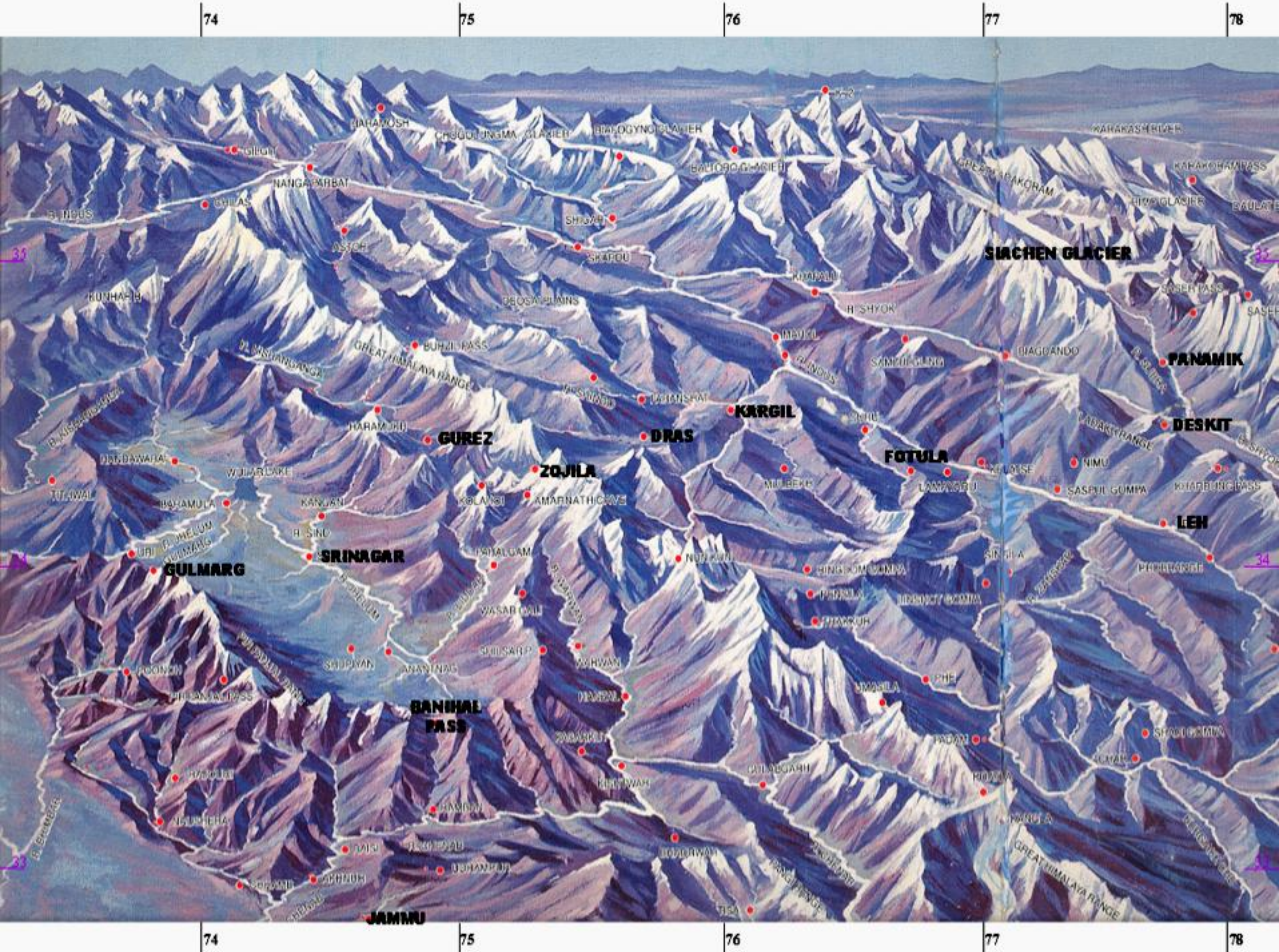




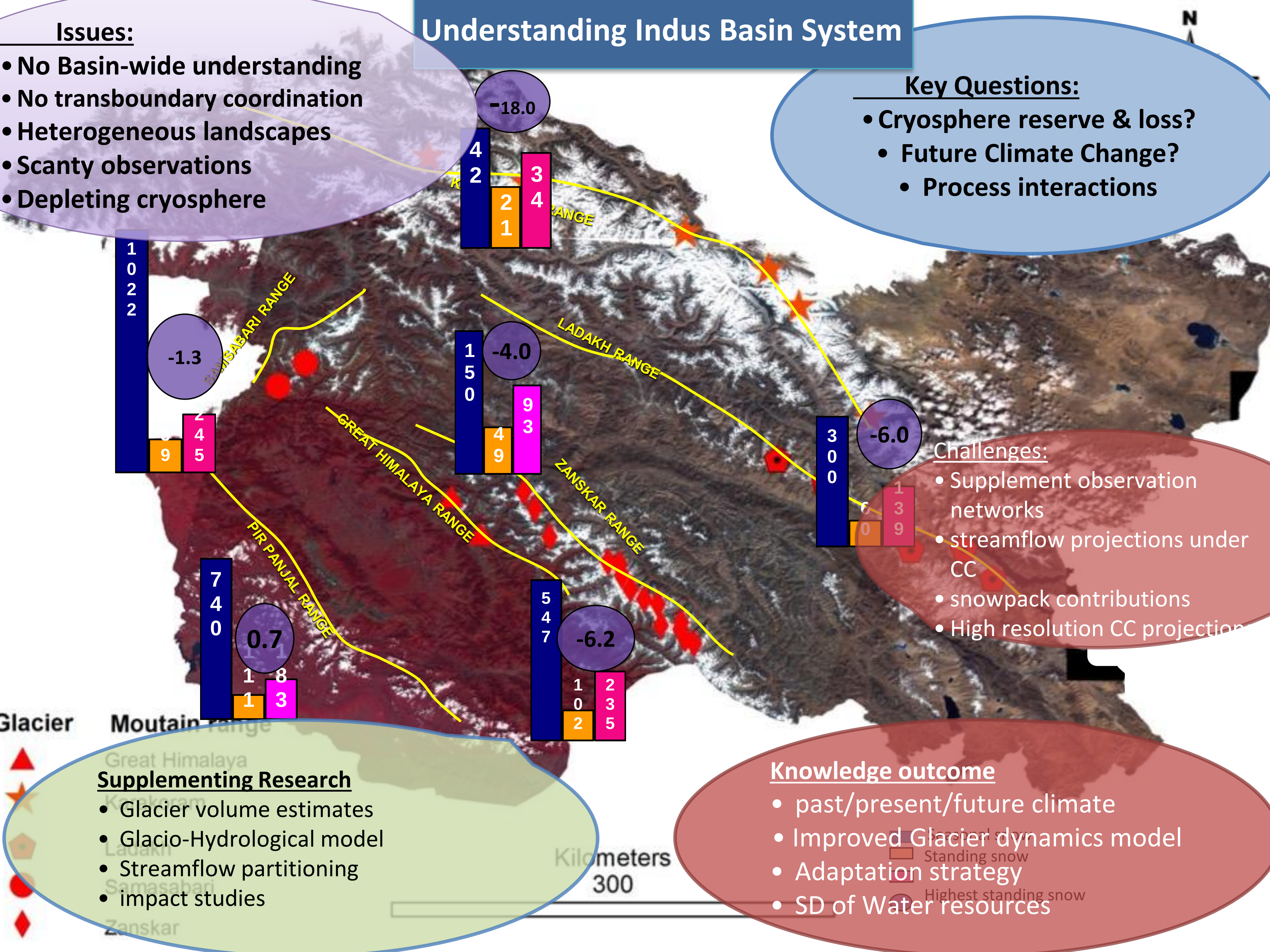
- **Number of glaciers (>0.02 km²):** 54,252
- **Glaciated area:** 60,000 km²
- **Estimated ice reserves:** 6,100 km³
- **Average glacier size:** ~1.1 km²
- **Largest glacier:** Siachen glacier, Karakoram mountains, Indus basin, 926 km²
- **Lowest glacier terminus:** 2,400 masl (Indus basin)
- **Highest glacier terminus:** 8,800 masl (Ganges basin)
- **Largest glaciated area concentration:** 5,000–6,000 masl


Regional cumulative mass change of reference glaciers
Cumulative mass change in [m w.e.] or [1,000 kg m⁻²]
Years
Asia Central
Arctic Canada North
Western Canada and USA
Caucasus and Middle East
Southern Andes
Alaska
Scandinavia
Svalbard and Jan Mayen
Central Europe
Mean of regions
Cumulative values relative to 1976.
Source: WGMS


c
glaciological mass balance (m w.e. yr-1)
-1.43 - -1.01
-1.00 - -0.76
-0.75 - -0.51
-0.50 - -0.26
-0.25 - 0.00
KH
RL
GR
GG
TB
DG
NN
SR
HT
CS
SG
ND
DR
CB
RS
KW
CN
PK
YL
AX
MR
CG
GL
Kilometers
0 125 250 500
Source: Azam et al., 2018, JoG



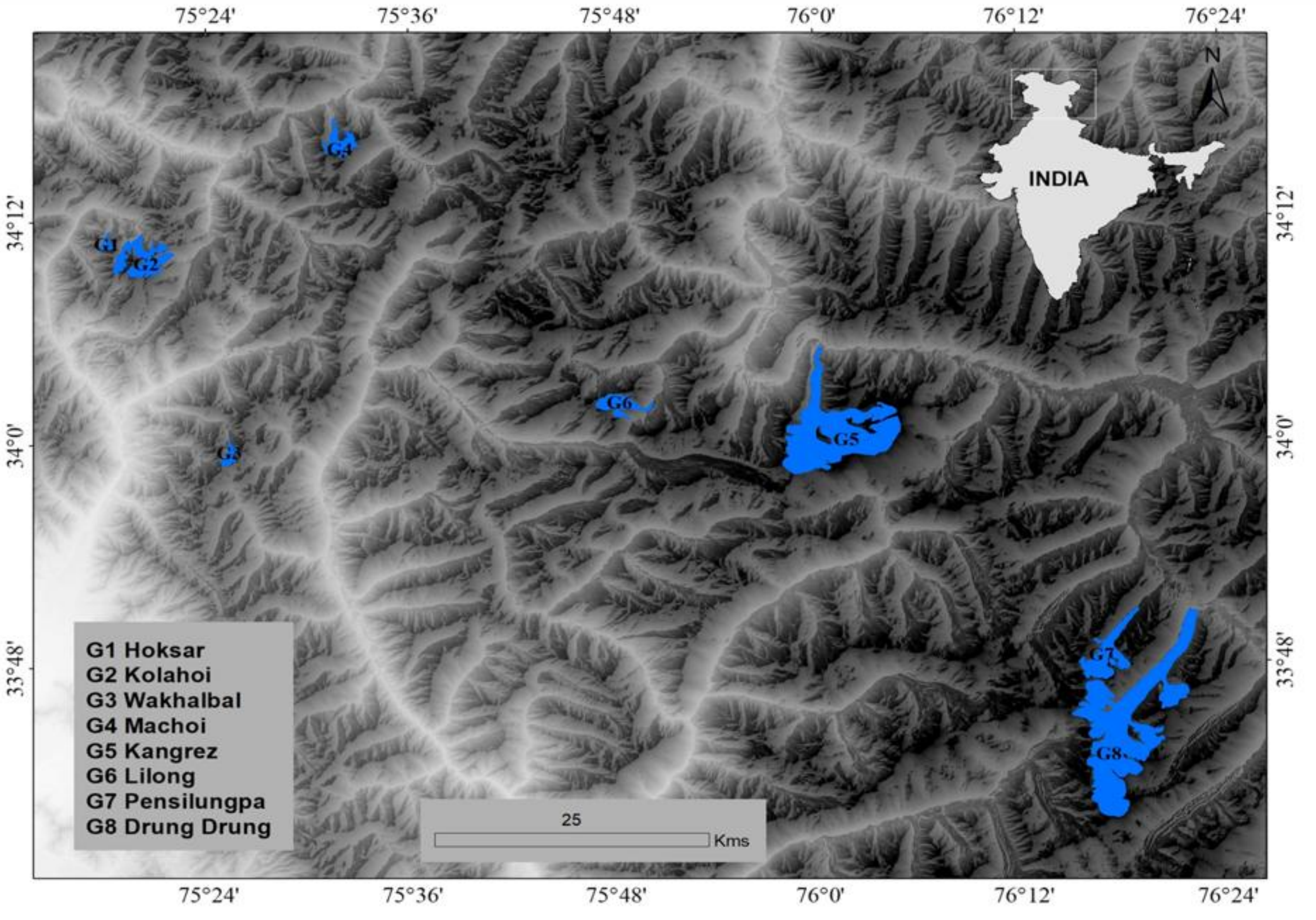
74
75
76
77
78
K-2
HARAMOSH
GILGIT
NANGA PARBAT
CHILAS
R. INDUS
ASTOR
SHIGAR
SKARDU
BALTORO GLACIER
KARAKASH RIVER
KARAKORAM PASS
SIACHEN GLACIER
KHAPALU
R. SHYOK
DEOSAI PLAINS
KUNHAR R
BURZIL PASS
GREAT HIMALAYA RANGE
R. KISHANGANGA
R. INDUS
SANKOO
KARGIL
PANAMIK
DESKIT
HARAMUKH
GUREZ
DRAS
ZOJILA
FOTULA
LAMAYURU
NIMU
SASPUL GUMPA
KHARDUNG PASS
WULAR LAKE
BARAMULA
KANGAN
KOLAHOI
AMARNATH CAVE
MULBEKH
LEH
R. SIND
R. JHELUM
URI
GULMARG
SRINAGAR
PAHALGAM
NUN KUN
PENSILA
R. JHELUM
SHOPIYAN
ANANTNAG
POONCH
PIR PANJAL PASS
BANIHAL
PASS
PHE
PADAM
KISHTWAR
UDHAMPUR
JAMMU
GREAT HIMALAYA RANGE
33
34
35


Understanding Indus Basin System
Issues:
• No Basin-wide understanding
• No transboundary coordination
• Heterogeneous landscapes
• Scanty observations
• Depleting cryosphere
Key Questions:
• Cryosphere reserve & loss?
• Future Climate Change?
• Process interactions
Challenges:
• Supplement observation networks
• streamflow projections under CC
• snowpack contributions
• High resolution CC projections
Supplementing Research
• Glacier volume estimates
• Glacio-Hydrological model
• Streamflow partitioning
• impact studies
Knowledge outcome
• past/present/future climate
• Improved Glacier dynamics model
• Adaptation strategy
• SD of Water resources
N
-18.0
42
21
34
1022
9
245
-1.3
150
49
93
-4.0
300
0
139
-6.0
740
11
83
0.7
547
102
235
-6.2
SAMSABARI RANGE
LADAKH RANGE
GREAT HIMALAYA RANGE
ZANSKAR RANGE
PIR PANJAL RANGE
Glacier
Great Himalaya
Zanskar
Kilometers
300
Standing snow
Highest standing snow

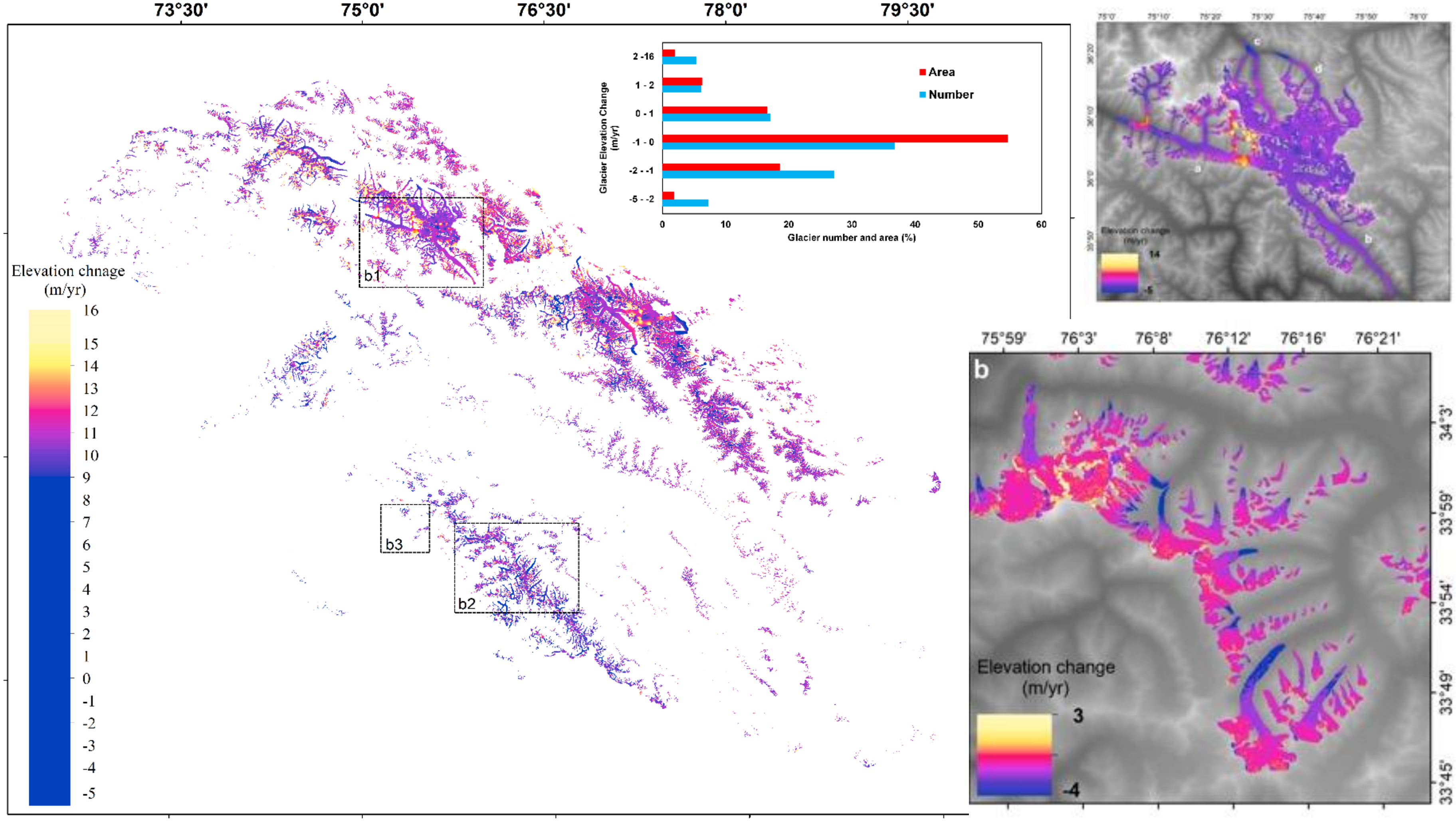
KEY QUESTIONS

- How much water is stored in cryosphere and how it moves through the system
- How will future climate change affect the water resources of the region?
- How can we make best use of the available datasets to understand the interactions of snow, glaciers, and river flows in the basin under changing climate
- How can the projections of climate change impacts in the basin be improved by coupling new high resolution downscaled RCM climatology to new process-based glacio-hydrological models?

GROUND BASED GLACIER STUDIES



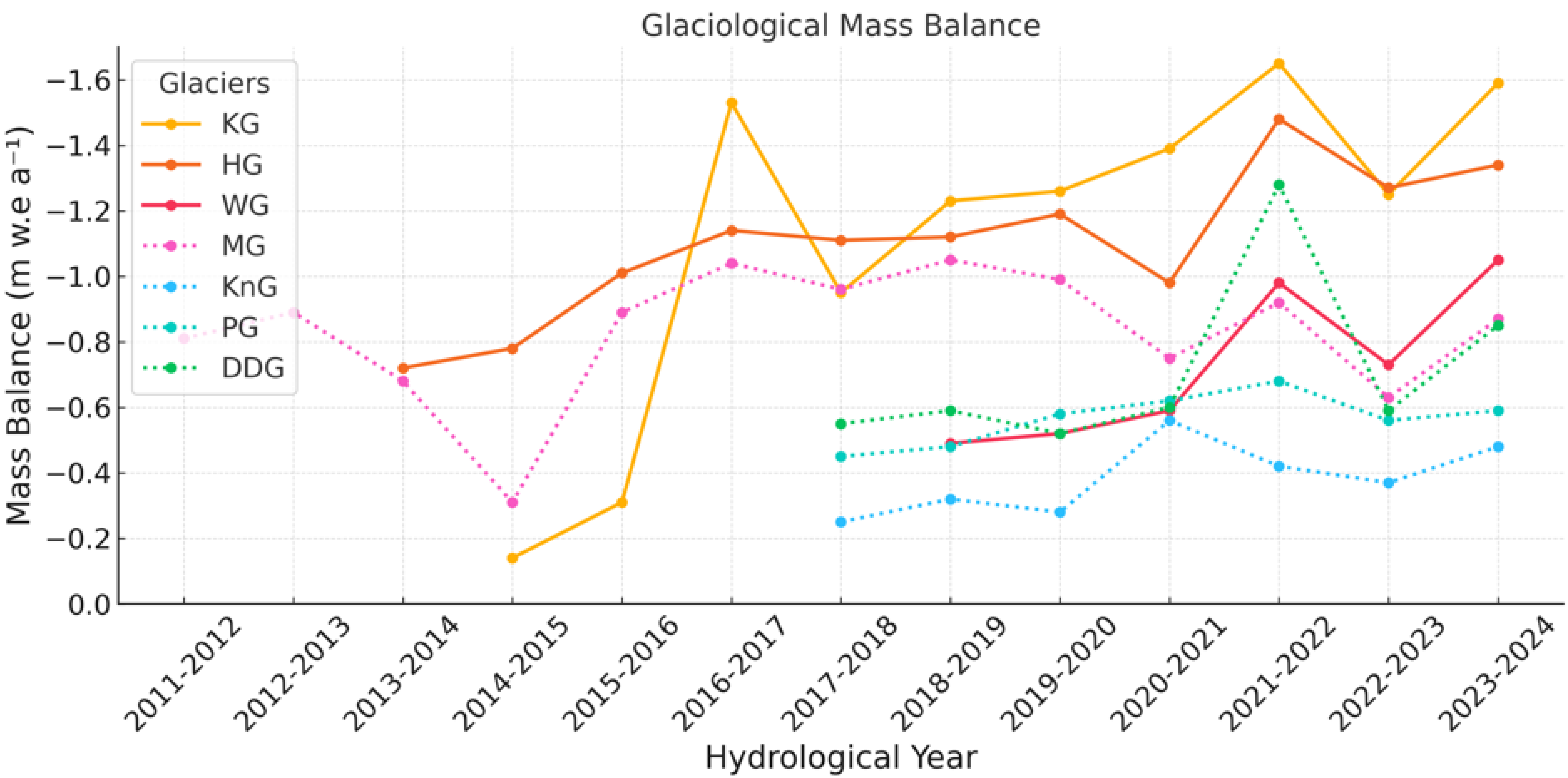
OVERALL GLACIER THICKNESS AND MASS CHANGES



dH/dT (m a⁻¹)	Mass balance m w.e. a⁻¹	Cumulative mass change Gt	Mass change Gt a⁻¹	Specific mass change kg a⁻¹ m⁻²
-0.40 ±0.37	-0.34 ±0.31	-67.07 ±5.08	-4.7±0.36	- 242.85

Glacier thickness across the mountain ranges UIB

Mountain Range	Area km²	dH/dT	Mean Elevation
		m/yr	m
KKR (7774*)	18009.46	0.13 ±0.35	5263
LR (3951)	2657.49	-0.31 ±0.25	5690
ZR (1933)	2534.12	-1.10 ±0.71	4994
SR (937)	677.49	-1.28 ±0.86	4738
GHR (254)	98.97	-1.03 ±0.64	4464
PPR (155)	44.46	-1.79 ±1.40	4225
150064	**24022 ±1401 km²**		



Glaciological Mass Balance
Glaciers
KG
HG
WG
MG
KnG
PG
DDG
Mass Balance (m w.e a⁻¹)
−1.6
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
2011-2012
2012-2013
2013-2014
2014-2015
2015-2016
2016-2017
2017-2018
2018-2019
2019-2020
2020-2021
2021-2022
2022-2023
2023-2024
Hydrological Year

Glaciological mass balance (m w.e a^{-1})

Hydrological Year	KG	HG	WG	MG	KnG	PG	DDG
2011-2012	-	-	-	-0.81	-	-	-
2012-2013	-	-	-	-0.89	-	-	-
2013-2014	-	0.72±0.35	-	-0.68	-	-	-
2014-2015	0.14±0.34	0.78±0.35	-	-0.31±0.3	-	-	
2015-2016	0.31±0.34	1.01±0.35	-	-0.89±0.30	-	-	-
2016-2017	1.53±0.34	1.14±0.35	-	-1.04±0.30	-	-	-
2017-2018	0.95±0.34	1.11±0.35	-	-0.96±0.30	-0.25±0.36	-0.45±0.36	-0.55±0.37
2018-2019	1.23±0.34	1.12±0.35	-0.49±0.33	-1.05±0.30	-0.32±0.36	-0.48±0.36	-0.59±0.37
2019-2020	1.26±0.28	1.19±0.35	-0.52±0.33	-0.99±0.30	-0.28±0.36	-0.58±0.36	-0.52±0.37
2020-2021	1.39±0.28	0.98±0.35	-0.59±0.33	-0.75±0.30	-0.56±0.36	-0.62±0.36	-0.60±0.37
2021-2022	1.65±0.28	1.48±0.35	-0.98±0.33	-0.92±0.30	-0.42±0.36	-0.68±0.36	-1.28±0.37
2022-2023	1.25±0.28	1.27±0.35	-0.73±0.33	-0.63±0.30	-0.37±0.36	-0.56±0.36	-0.59±0.37
2023-2024	1.59±0.28	1.34±0.35	-1.05±0.33	-0.87±0.30	-0.48±0.36	-0.59±0.36	-0.85±0.37

Glaciological mass balance (m w.e a^{-1})							
Hydrological Year	KG	HG	WG	MG	KnG	PG	DDG
2011-2012	-	-	-	-0.81	-	-	-
2012-2013	-	-	-	-0.89	-	-	-
2013-2014	-	0.72±0.35	-	-0.68	-	-	-
2014-2015	0.14±0.34	0.78±0.35	-	-0.31±0.3	-	-	
2015-2016	0.31±0.34	1.01±0.35	-	-0.89±0.30	-	-	-
2016-2017	1.53±0.34	1.14±0.35	-	-1.04±0.30	-	-	-
2017-2018	0.95±0.34	1.11±0.35	-	-0.96±0.30	-0.25±0.36	-0.45±0.36	-0.55±0.37
2018-2019	1.23±0.34	1.12±0.35	-0.49±0.33	-1.05±0.30	-0.32±0.36	-0.48±0.36	-0.59±0.37
2019-2020	1.26±0.28	1.19±0.35	-0.52±0.33	-0.99±0.30	-0.28±0.36	-0.58±0.36	-0.52±0.37
2020-2021	1.39±0.28	0.98±0.35	-0.59±0.33	-0.75±0.30	-0.56±0.36	-0.62±0.36	-0.60±0.37
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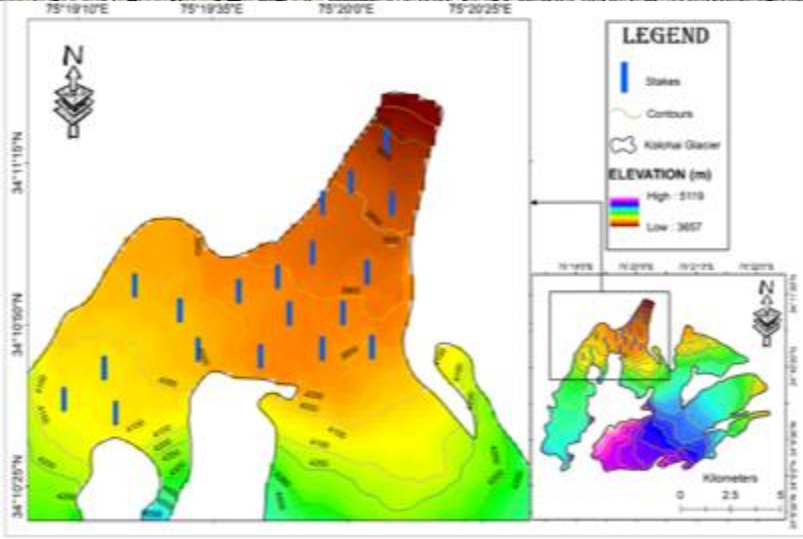
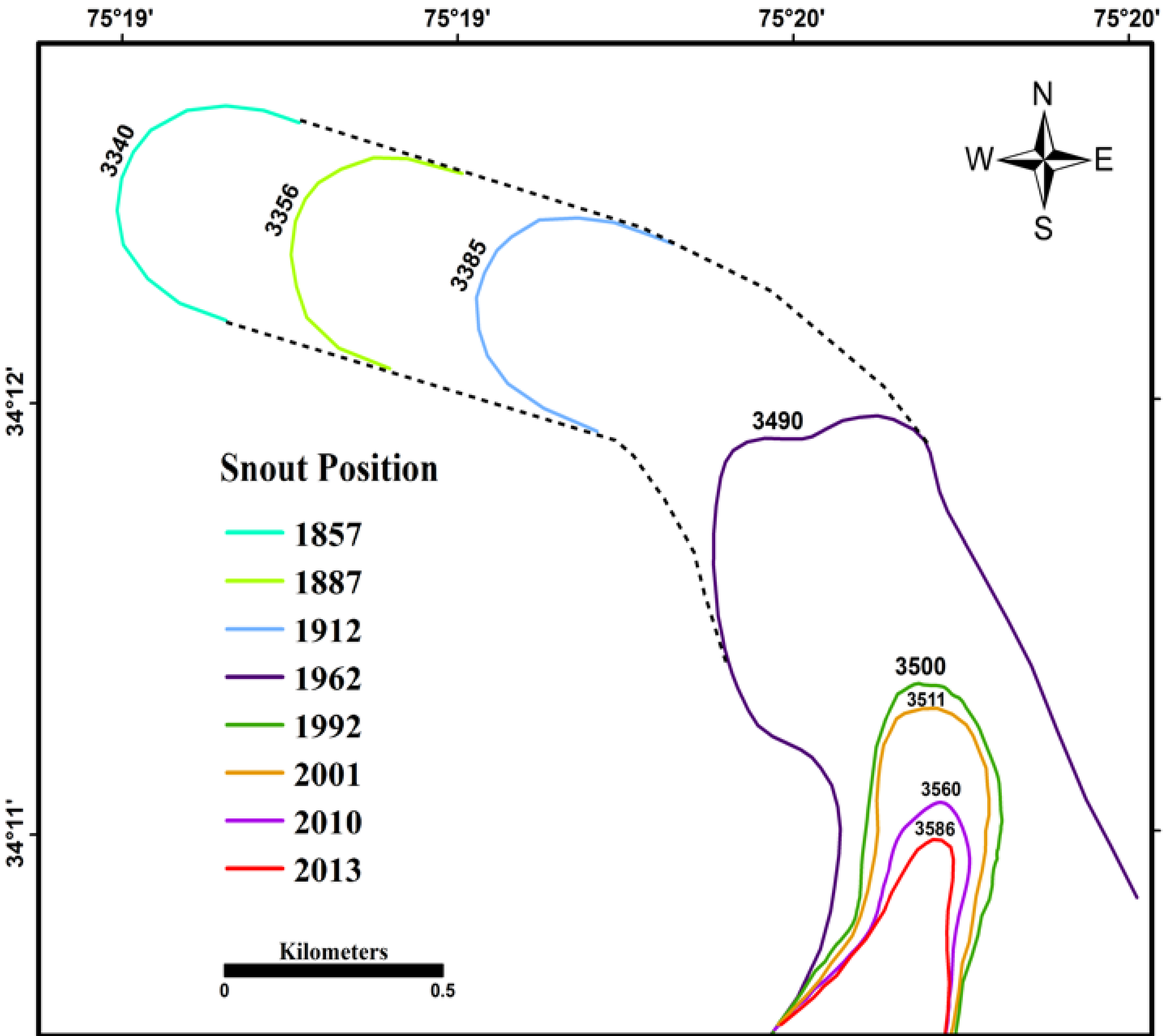
2022-2023	1.25±0.28	1.27±0.35	-0.73±0.33	-0.63±0.30	-0.37±0.36	-0.56±0.36	-0.59±0.37
2023-2024	1.59±0.28	1.34±0.35	-1.05±0.33	-0.87±0.30	-0.48±0.36	-0.59±0.36	-0.85±0.37


75°19'10"E
75°19'35"E
75°20'0"E
75°20'25"E
N
LEGEND
Stakes
Contours
ELEVATION (m)
High : 5119
Low : 3657
Kilometers
0
2.5
5

SNOUT MONITORING OF KOLAHOI GLACIER



Romshoo, Shakil Ahmad, Khalid Omar Murtaza and Tariq Abdullah (2022). Towards understanding various influences on mass balance of the Hoksar Glacier in the Upper Indus Basin using observations. *Scientific Reports, (2022) 12:15669.* https://doi.org/10.1038/s41598-022-20033-w (IF: 4.996)

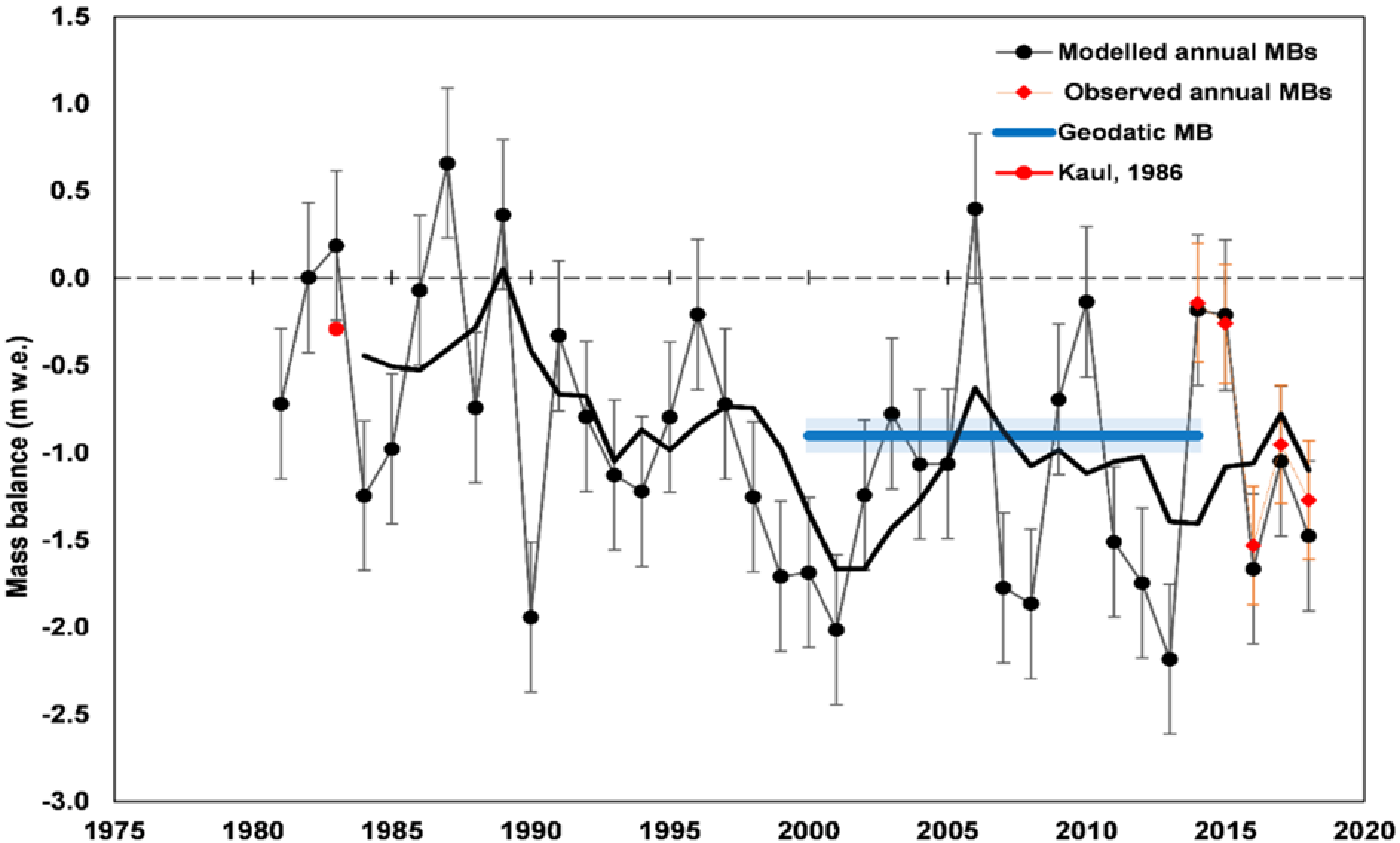
DIRECT, GEODETIC & MODELLED MB (KOLAHOI GLACIER)

Hydrological year*	Observed MB (m w.e.)	Modelled MB (m w.e.)
2014-15	-0.14 ±0.37	-0.18 ±0.42
2015-16	-0.31 ±0.37	-0.21 ±0.42
2016-17	-1.53 ±0.37	-1.67 ±0.42
2017-18	-0.95 ±0.37	-1.05 ±0.42
2018-19	-1.23 ±0.37	-1.48 ±0.42
2019-20	-1.13 ±0.37	-1.29 ±0.42
2020-21	-1.21 ±0.37	-
2021-22	-1.65 ±0.28	
2022-23	-1.25 ±0.28	
2023-24	-1.59 ±0.28	

Observed 2014-20	Modelled 2014-20	Geodetic 2000-14
-0.92 ±0.37	**-0.98±0.42**	**-0.90 ±0.09**

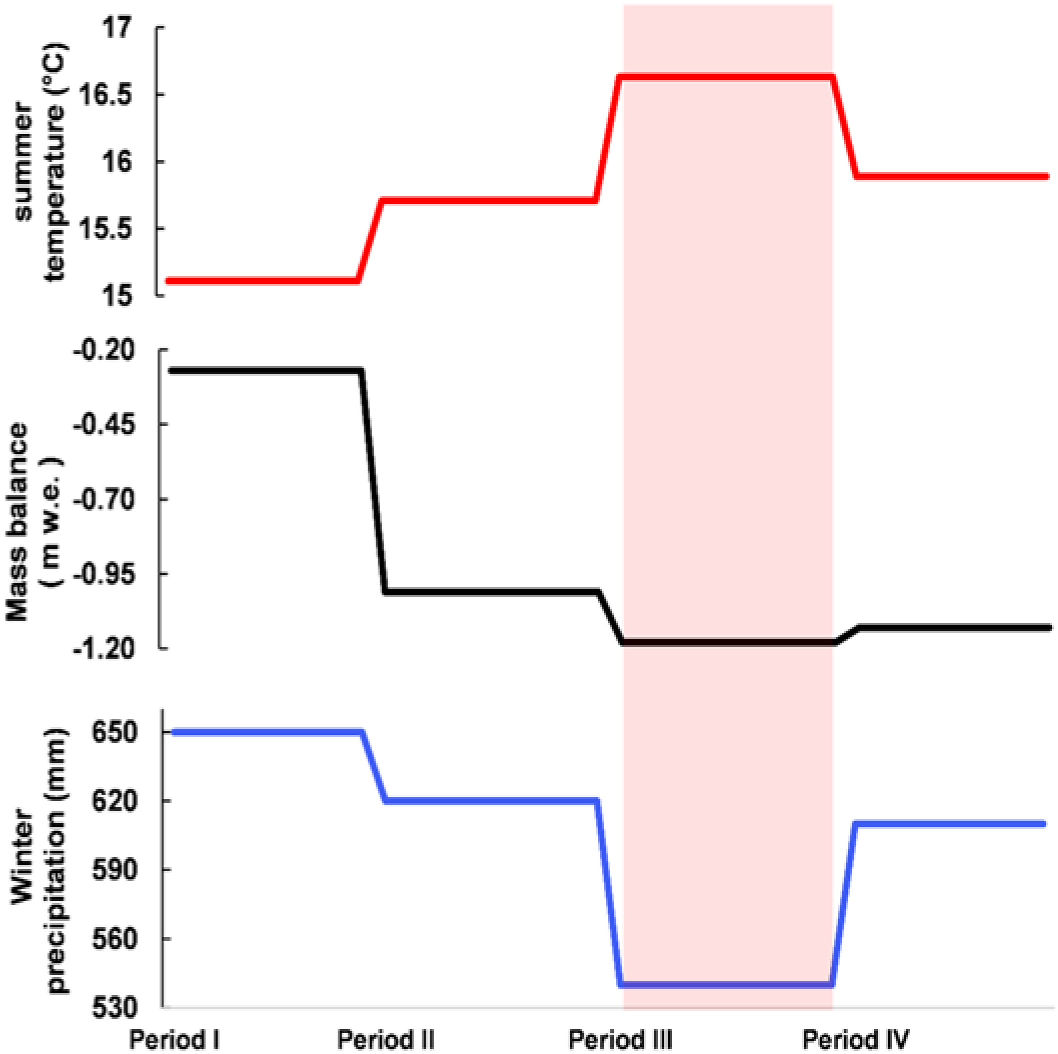
Romshoo et al.., 2023 (JoH)

FIELD BASED, GEODETIC AND MODELLED MB OF KOLAHOI GLACIER IN KASHMIR HIMALAYA



Source: Romshoo et al., 2023, JoH

MASS BALANCE OF KOLAHOI GLACIER AND THE CLIMATIC DRIVERS



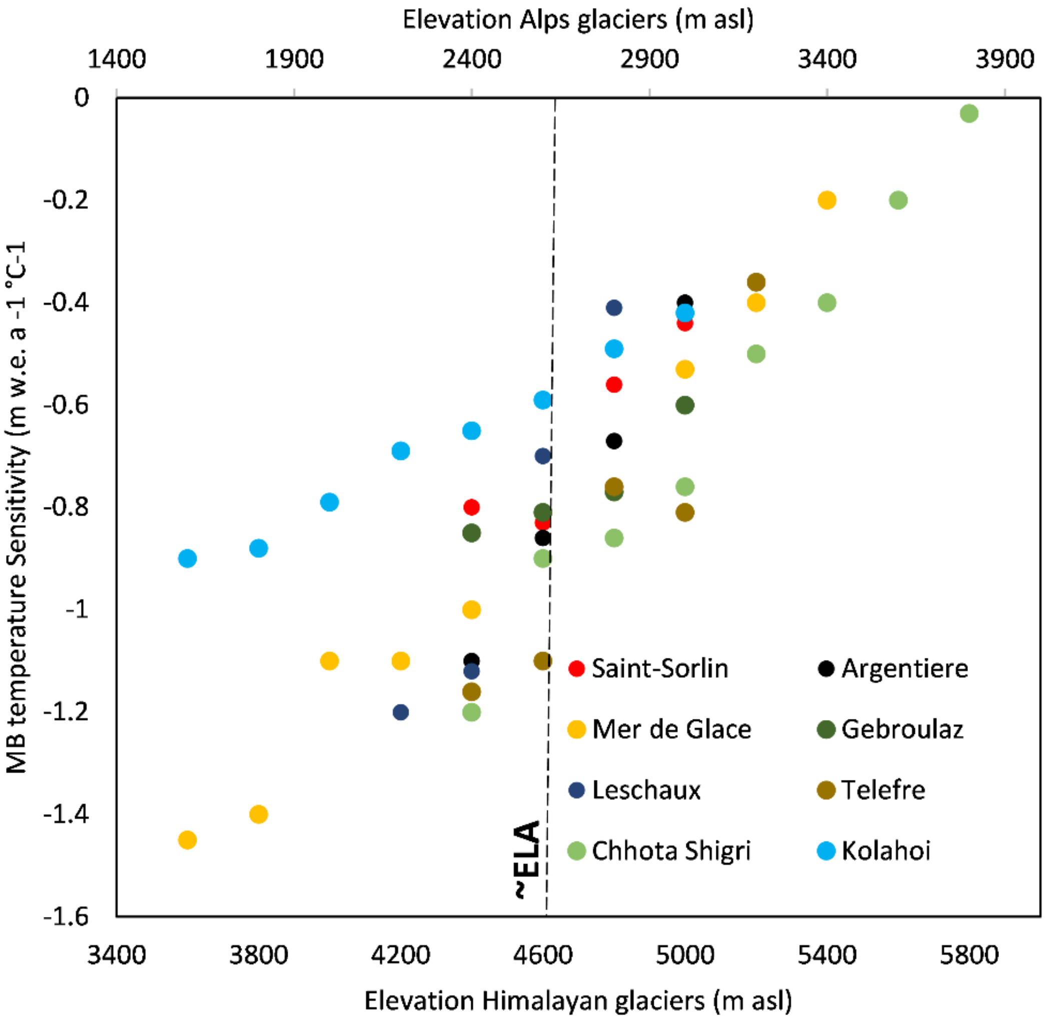
	MB (m w.e. a^{-1})	ST (°C)	WP (mm)
Period I (1980-90)	-0.27 ±0.42	15.11	650
Period II (1990-00)	-1.01 ±0.42	15.71	620
Period III (2000-10)	**-1.18 ±0.42**	**16.63**	**540**
Period IV (2010-2-19)	-1.13 ±0.42	15.89	610

ST: Summer temperature
WP: Winter precipitation

Average (1980-2019):
Summer temperature: 15.8 °C
Winter precipitation: 604 mm

Source: Romshoo et al., 2023, JoH

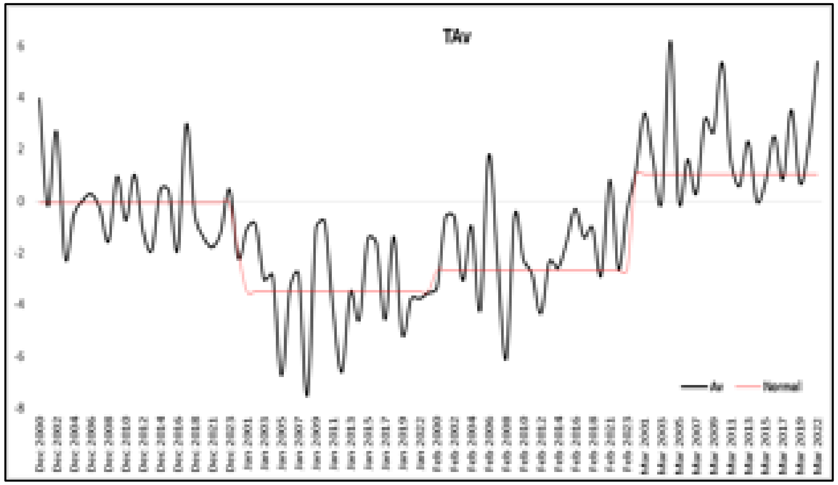
MB SENSITIVITY TO TEMPERATURE & PRECIPITATION

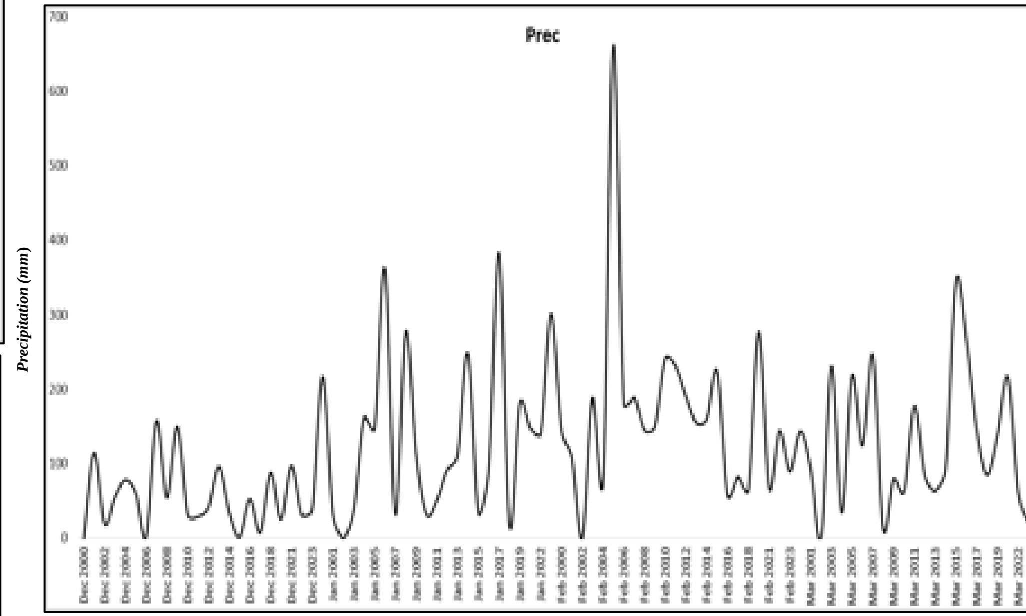


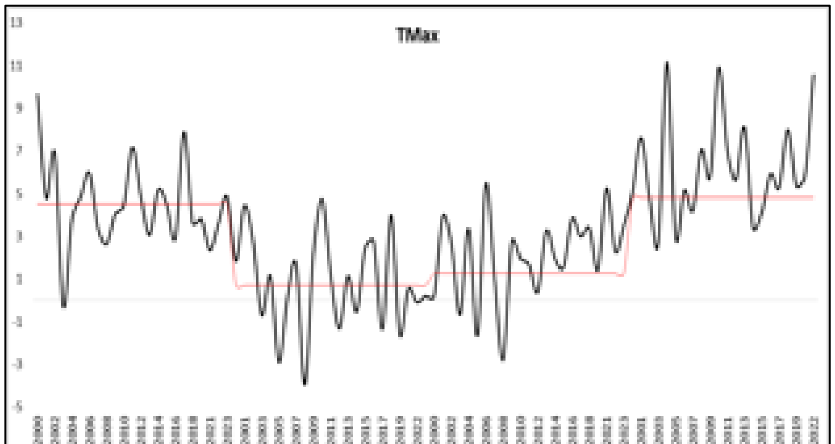
- ***The sensitivity of MB to temperature is -0.65 m w.e. a^{-1}° C^{-1},whereas the sensitivity to precipitation is calculated as ~0.13 m w.e. a^{-1} for a 10% change.***

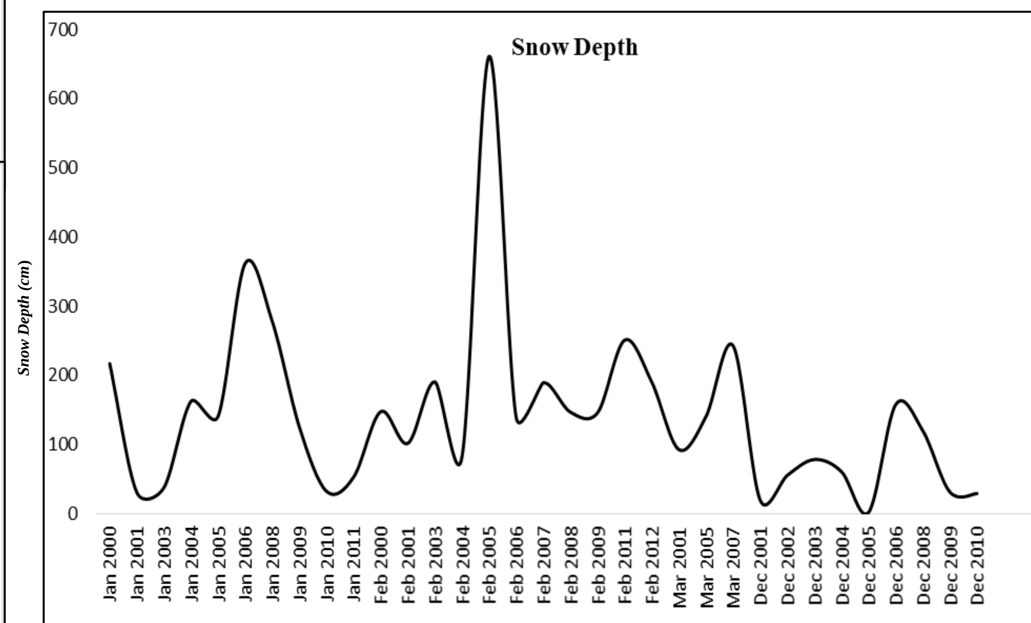
- ***~48% increase in precipitation is required to offset the impacts of 1°C increase in temperature on glacier MB.***

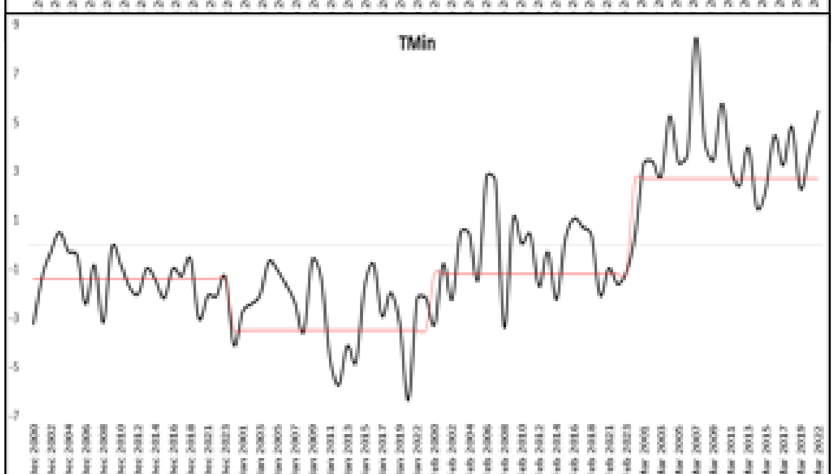
RECENT WARMING TRENDS IN THE KASHMIR HIMALAYA











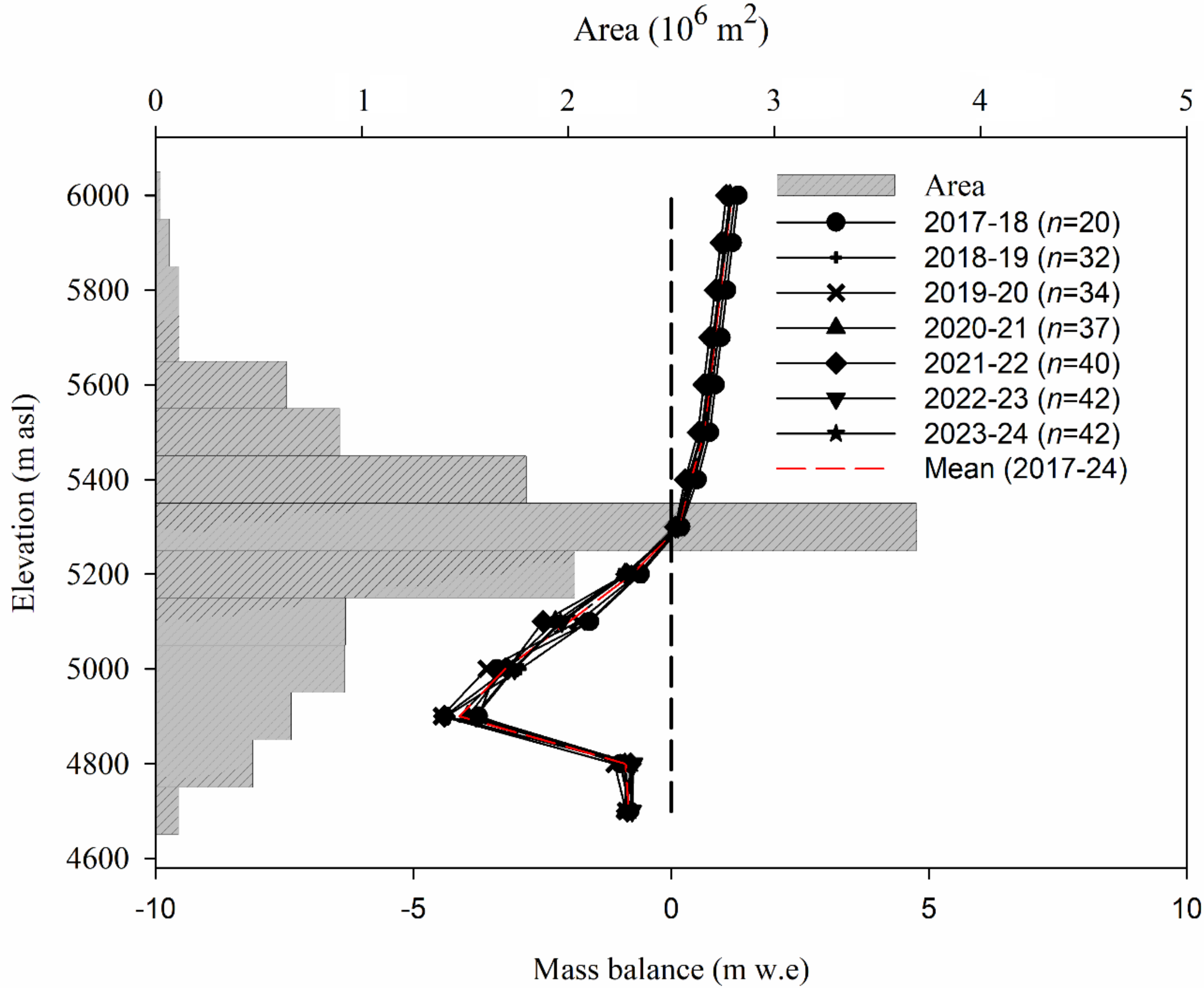
RECENT GLACIER MELTING IN THE UIB

RECENT GLACIER MELTING IN THE ALPS

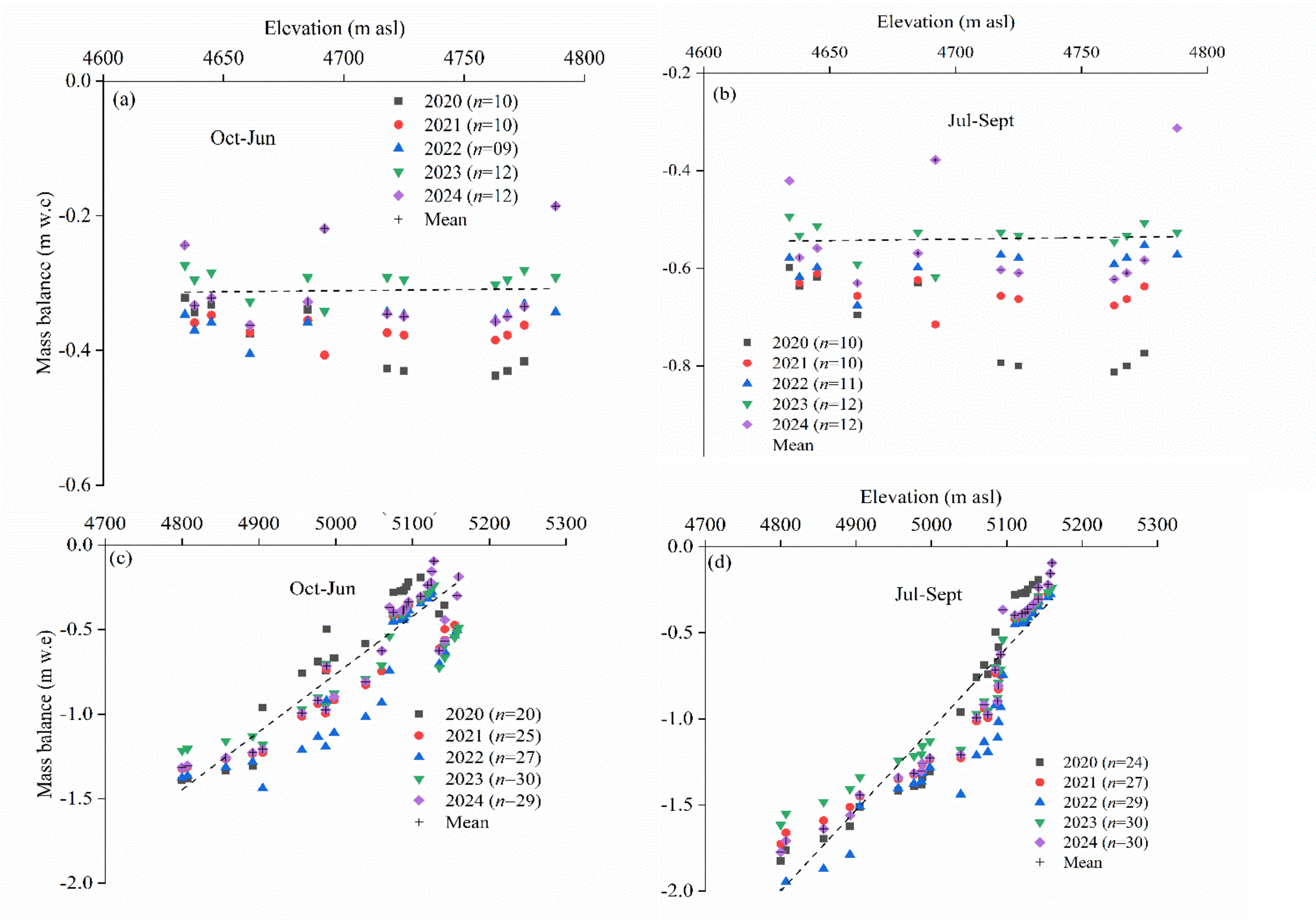
RECENT GLACIER MELTING IN UIB

Glacier Name	Region/Basin	Average Melt (m)										
		2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24
Drang-Drung	Ladakh	-	-	-	-	-4.52	-4.61	-4.54	-4.99	**-6.15**	-5.78	-5.9
PG	Ladakh	-	-	-	-	-2.07	-2.06	-1.99	-2.03	**-2.45**	-1.9	-2.2
Kangriz	Ladakh/	-	-	-		-4.11	-4.17	-4.08	-4.76	**-6.8**	-6.00	-6.4
Machoi	Ladakh/	-1.51	-0.24	-0.64	-2.16	-2.02	-2.24	-2.49	-2.67	**-3.18**	-2.67	-3.34
Kolahoi	Kashmir	-	-0.31	-0.69	-3.40	-2.11	-2.67	-2.73	-3.09	**-3.75**	-2.85	-3.4
Hoksar	Kashmir	-	-0.2	-0.56	-2.13	-1.22	-1.65	-1.86	-2.24	**-2.76**	-1.77	-1.91
Wakhalba	Kashmir	-	-	-	-	-1.22	-	-	-1.82	**-2.24**	-1.70	1.85

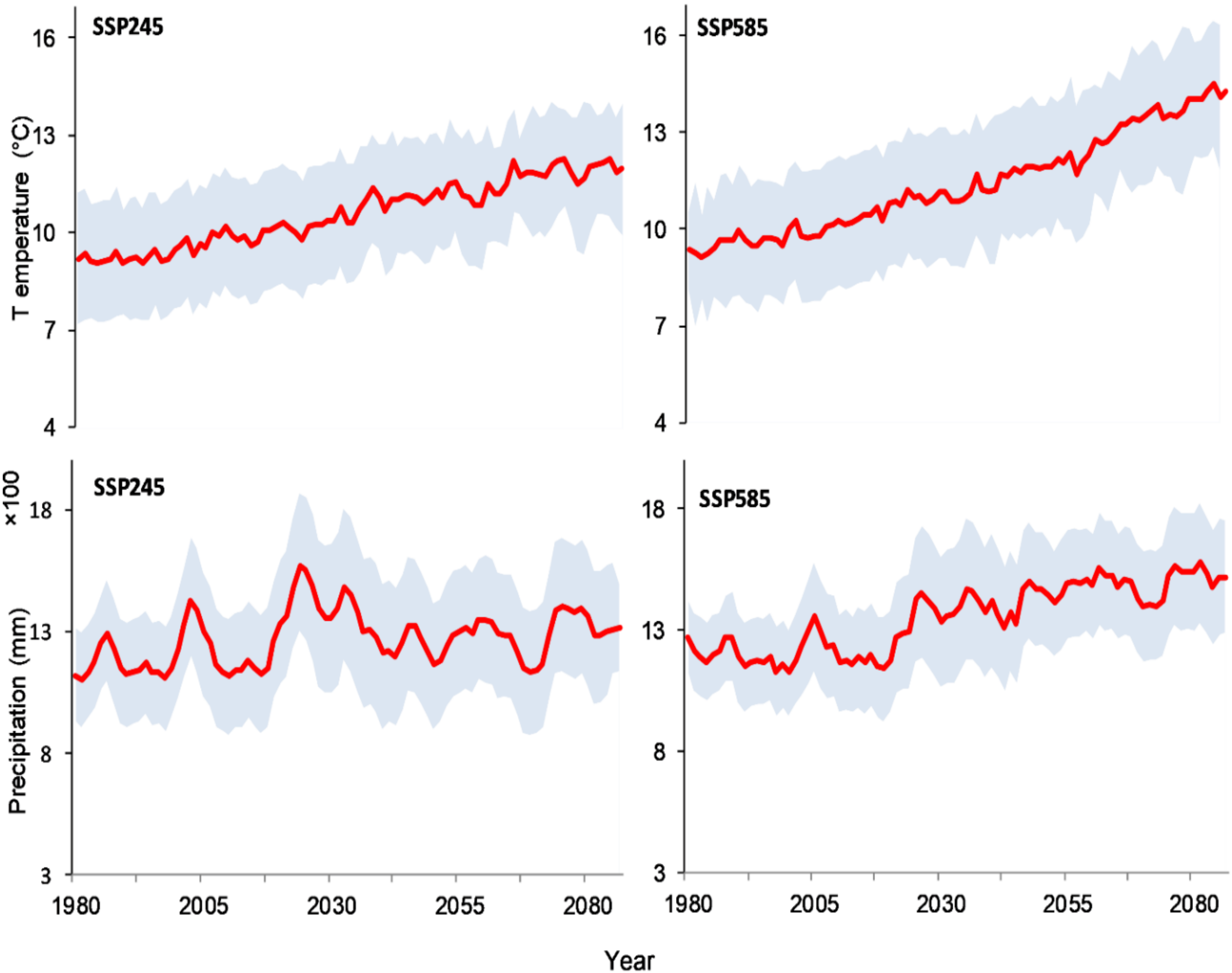
b
Boulder size measurement
a
G8
G7
G6
G5
G4
G3
G2
G1
Debris covered zone
N
c
Debris size measurement in 5m×5m grid
d
Debris thickness measurement
e
Ice cliffs
f
Table rocks
Supraglacial streams
g
Supraglacial pond

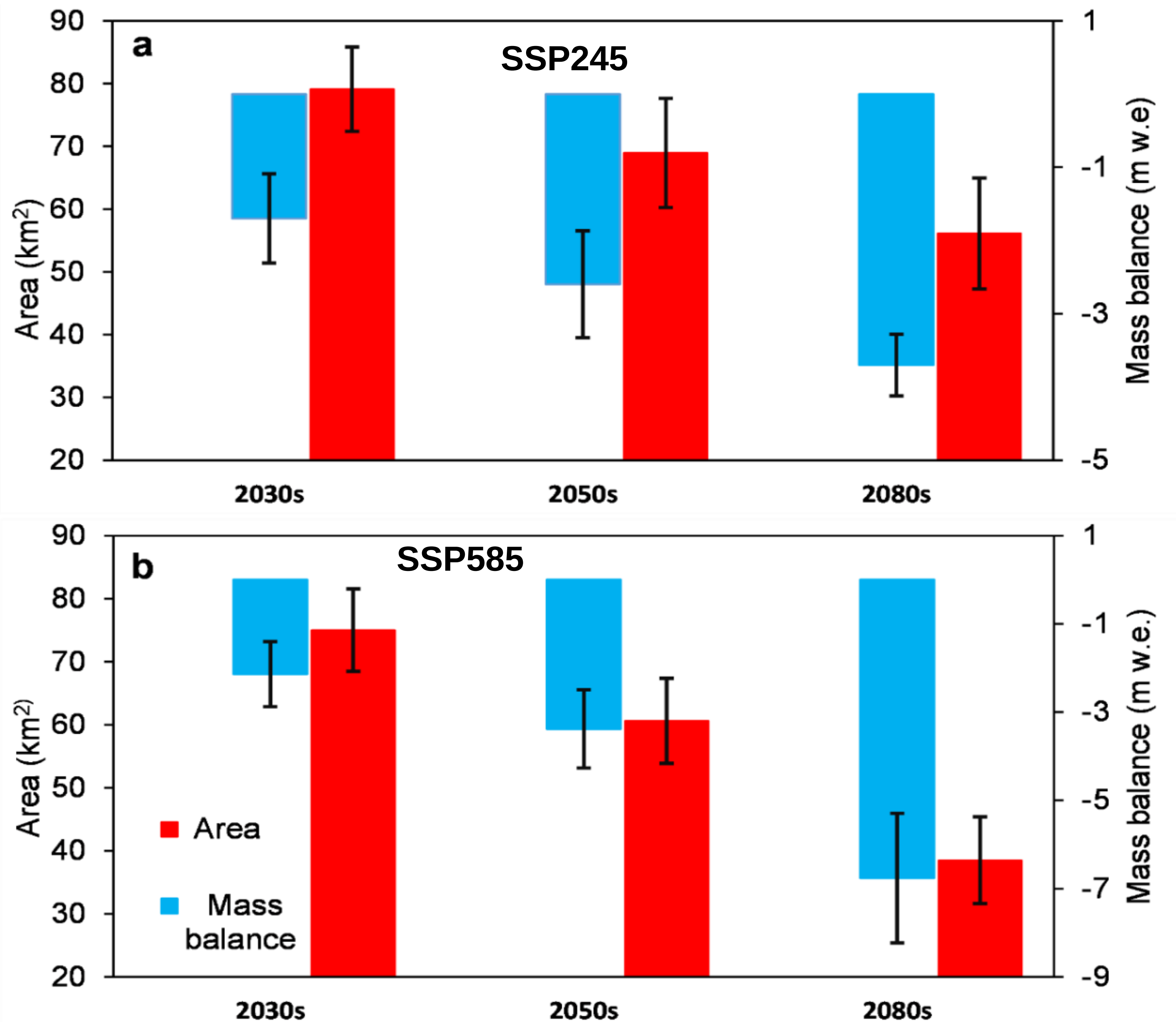


Area (10^6 m^2)
0
1
2
3
4
5
6000
5800
5600
5400
5200
5000
4800
4600
Elevation (m asl)
Area
2017-18 (n=20)
2018-19 (n=32)
2019-20 (n=34)
2020-21 (n=37)
2021-22 (n=40)
2022-23 (n=42)
2023-24 (n=42)
Mean (2017-24)
-10
-5
0
5
10
Mass balance (m w.e)



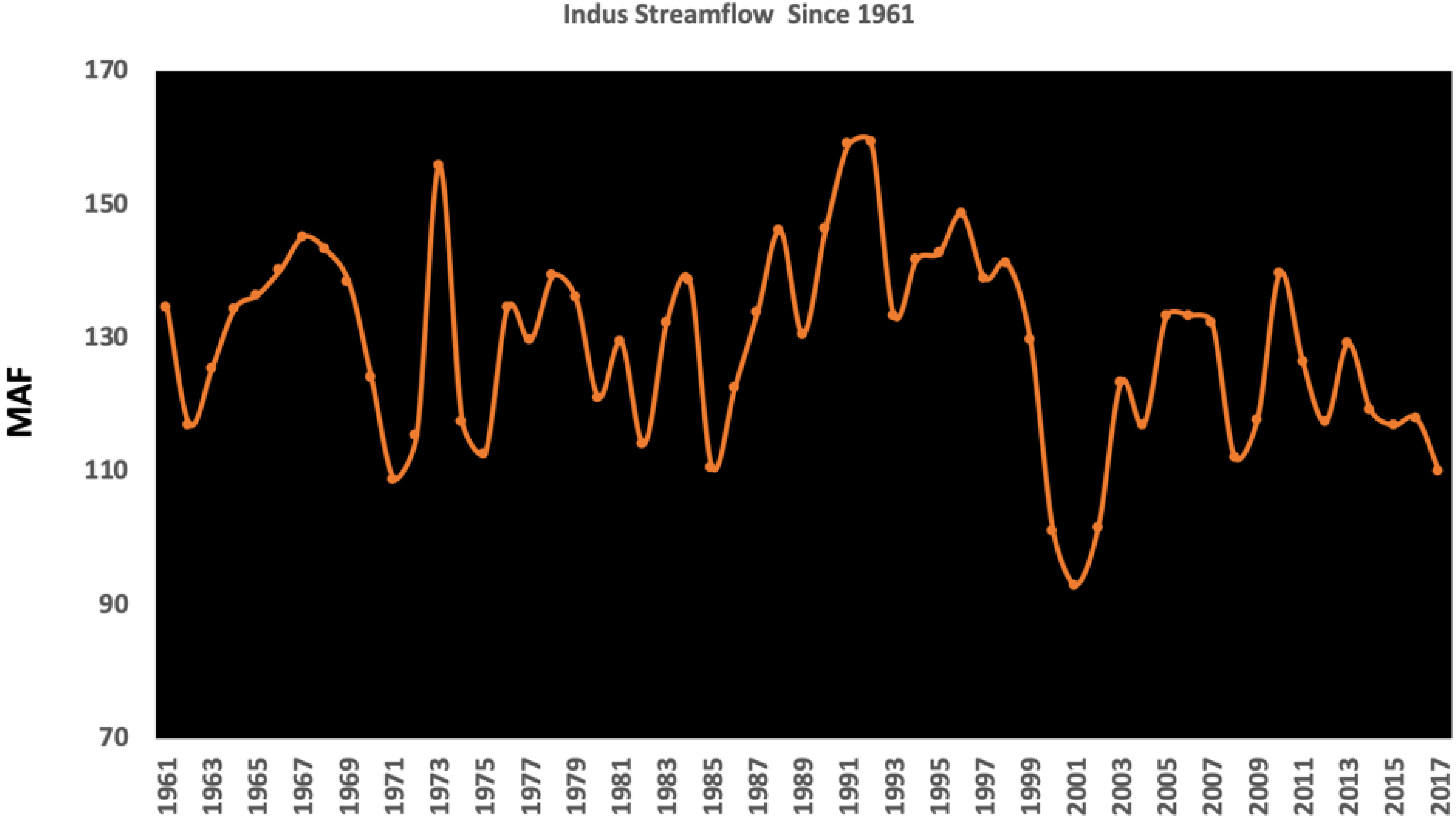
Elevation (m asl)
(a)
Oct-Jun
2020 (n=10)
2021 (n=10)
2022 (n=09)
2023 (n=12)
2024 (n=12)
Mean
Mass balance (m w.e)
(b)
Jul-Sept
2020 (n=10)
2021 (n=10)
2022 (n=11)
2023 (n=12)
2024 (n=12)
Mean
(c)
Oct-Jun
2020 (n=20)
2021 (n=25)
2022 (n=27)
2023 (n=30)
2024 (n=29)
Mean
(d)
Jul-Sept
2020 (n=24)
2021 (n=27)
2022 (n=29)
2023 (n=30)
2024 (n=30)
Mean


SSP245
SSP585
T emperature (°C)
16
13
10
7
4
SSP245
SSP585
×100
Precipitation (mm)
18
13
8
3
1980
2005
2030
2055
2080
Year

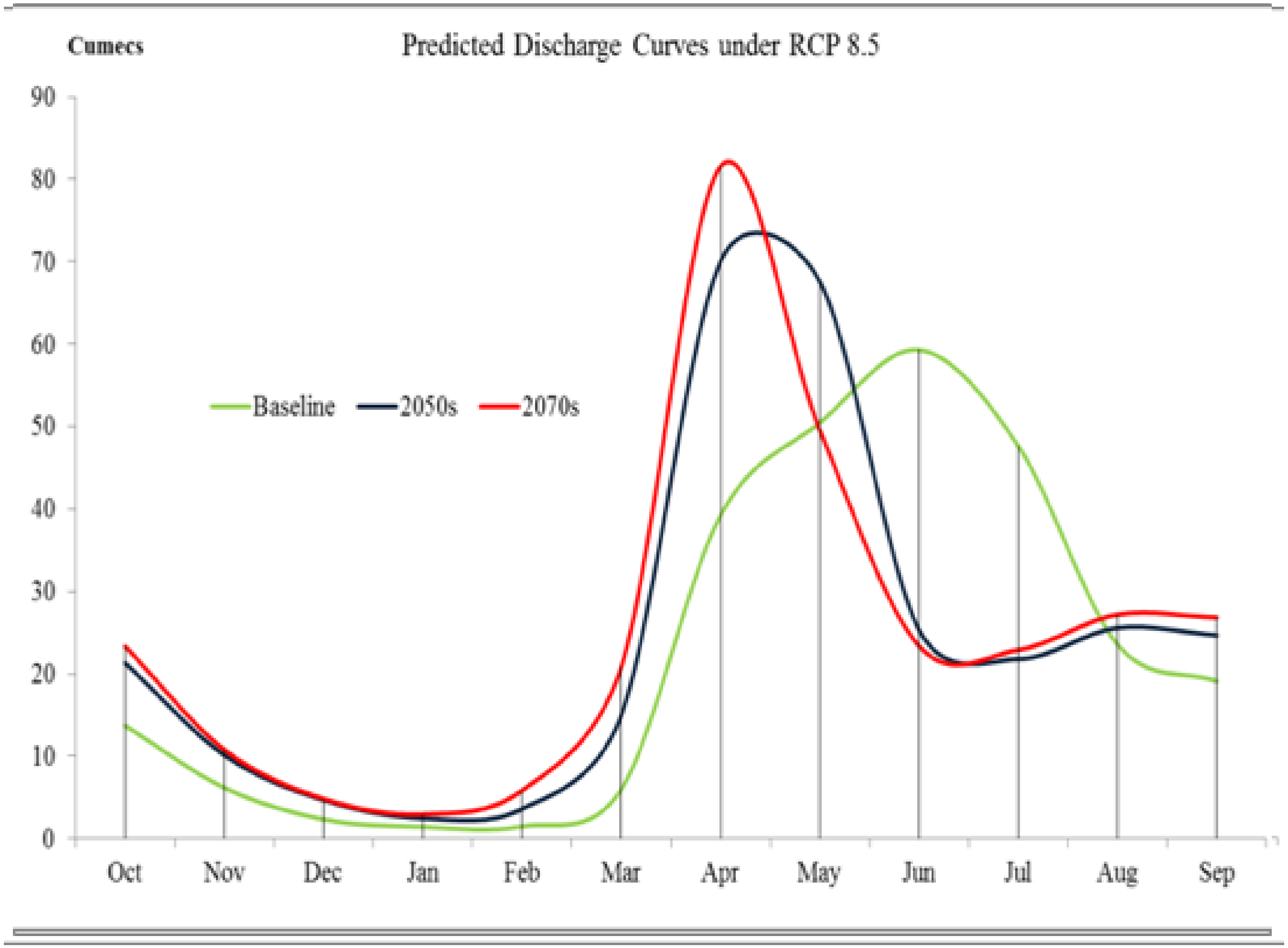


a
SSP245
Area (km2)
Mass balance (m w.e)
90
80
70
60
50
40
30
20
1
-1
-3
-5
2030s
2050s
2080s
b
SSP585
Area (km2)
Mass balance (m w.e.)
90
80
70
60
50
40
30
20
1
-1
-3
-5
-7
-9
Area
Mass balance
2030s
2050s
2080s

Climate change, Melting cryosphere and Streamflows



Hydrograph Changes under Changing



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CONCLUSIONS

- VERY COMPLEX GLACIER RESPONSE TO CLIMATE CHANGE
- GLACIER MELTING HAS ENHANCED RECENTLY
- SCANTY NETWORK OF GLACIOLOGICAL, HYDRLOGICAL AND METEOROLOGICAL OBSERVATIONS
- WE HAVE LOST ~ 25-30% OF THE GLACIAL MASS DURING THE LAST SIX DECADES BUT MORE OF THE GLACIAL MASS IS PREDICTED TO DISAPPEAR BY THE END OF 21ST CENTURY
- SIGNIFICANT DECLINE IN THE STREAMFLOWS SINCE 1990s DUE TO THE DEPLETION OF CRYOSPHERE
- SHIFTING HYDROGRAPH PEAKS, CHANGE IN THE FORM OF PRECIPITATION AND DEPLETING STREAMFLOWS ARE A MATTER OF CONCERN

TEAM

Thank you