Collaborative update Activities and Result

Hydrology, water availability and demand-basin scale (Group 4):

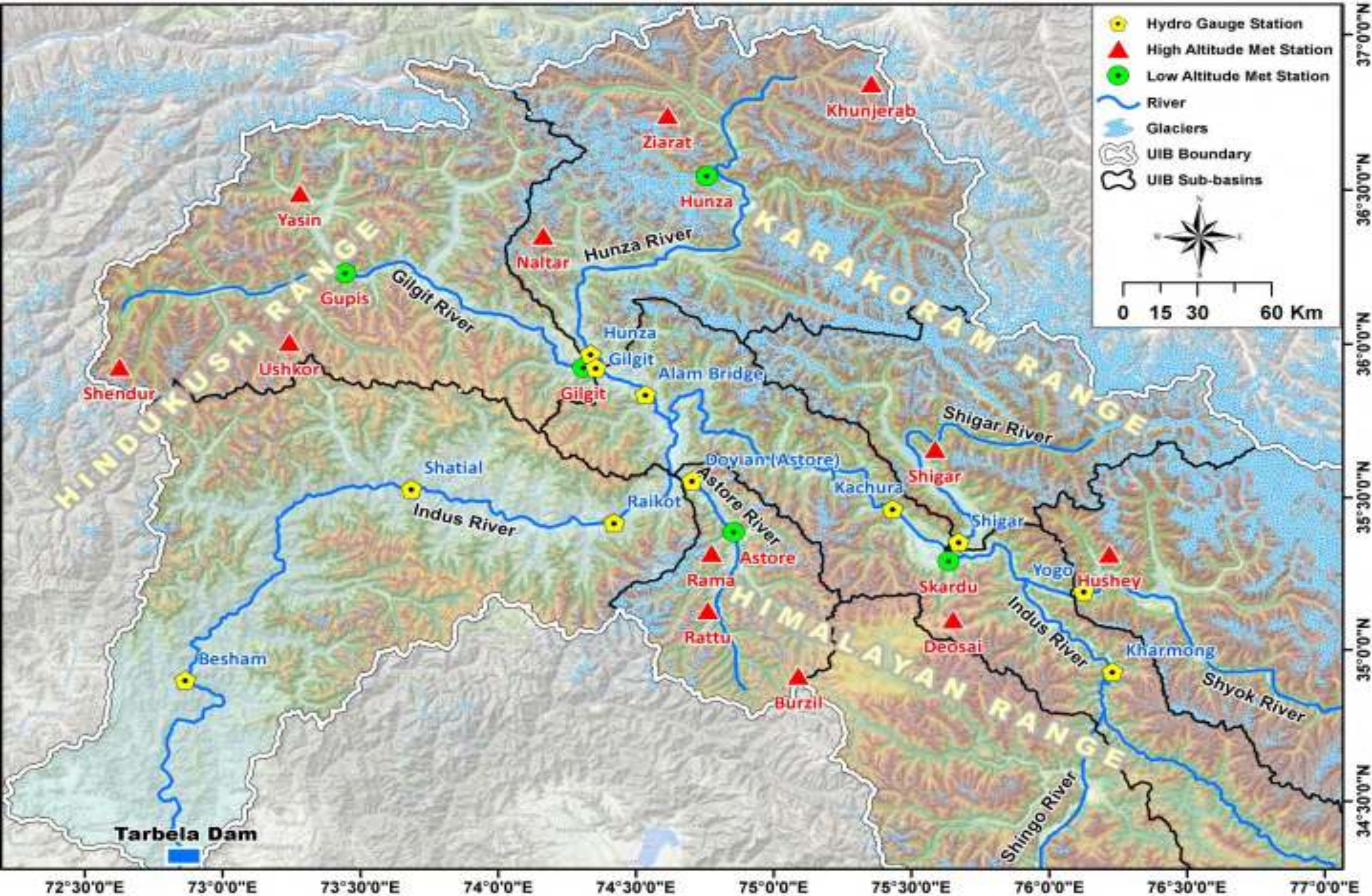
Yinsheng Zhang and Arun Shrestha

1. Observation network

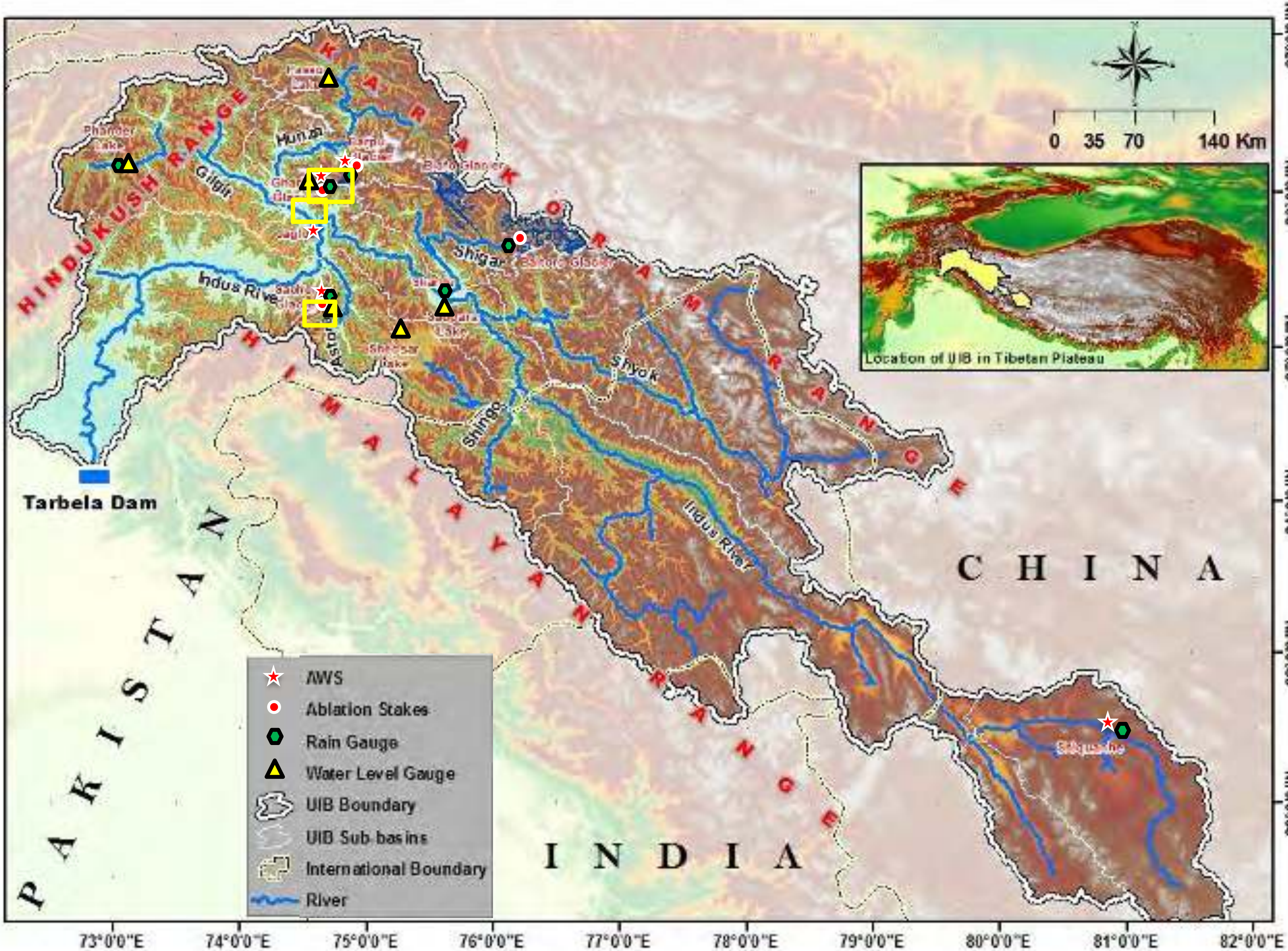
2. Update result on understanding UIB hydrological process

1）Glacio-hydrology
2）Water resource-discharge

Meteorological & Hydrological Stations of PMD and WAPDA in UIB

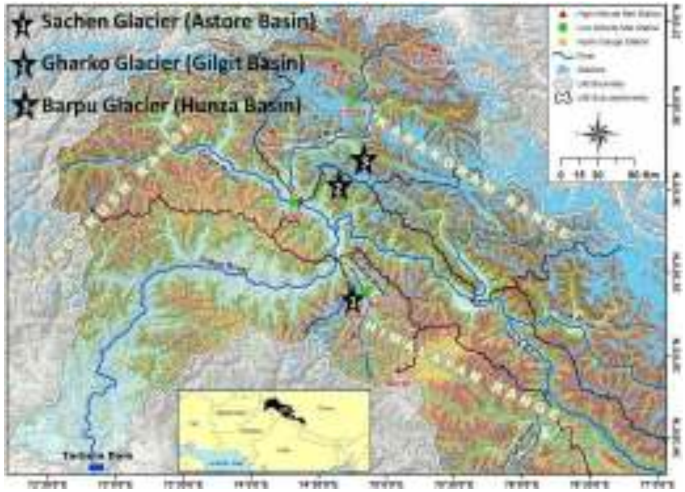


Hydrological Observation in UIB



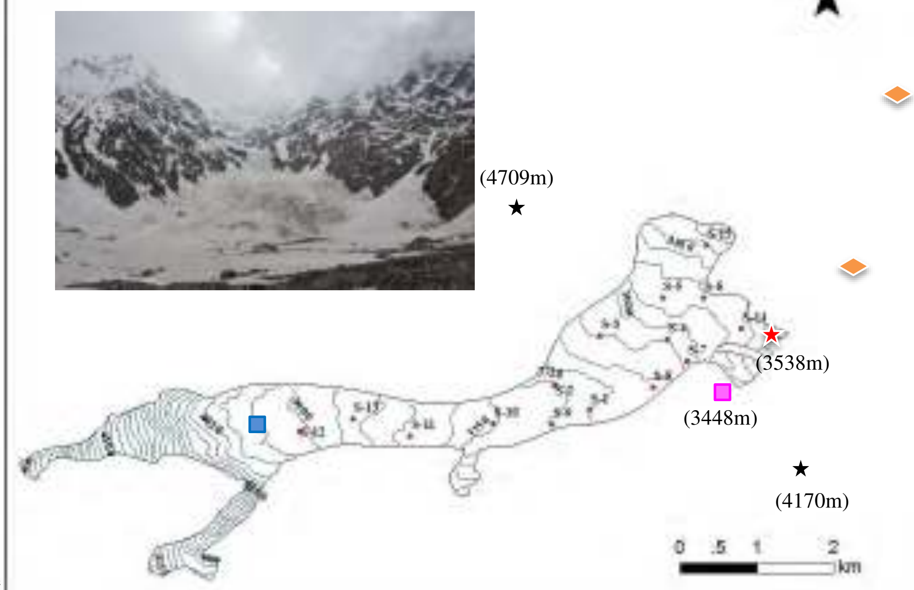
b. Glacier's Ablation Measurements & Mass Balance Studies in UIB

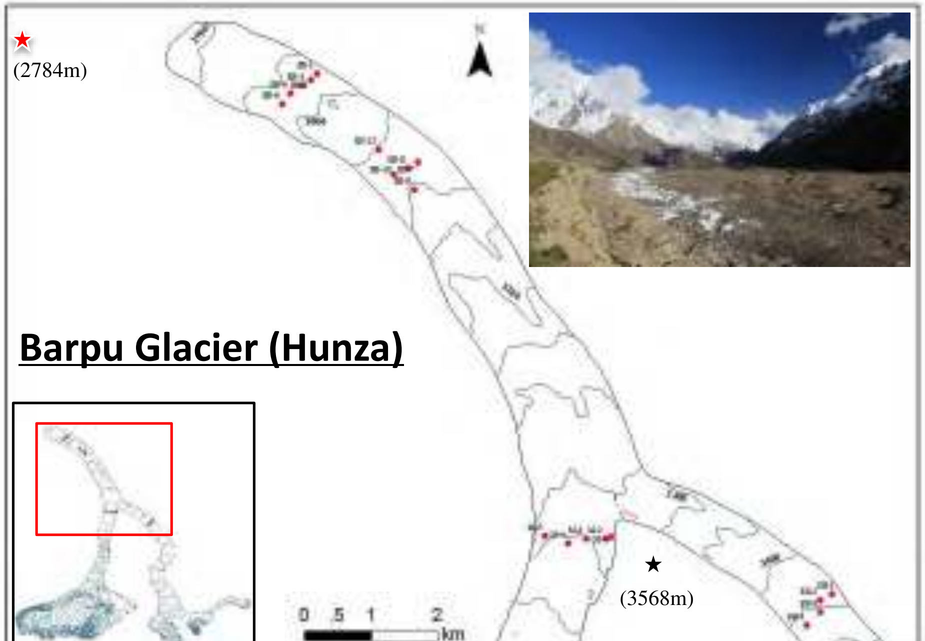
Ablation Stakes Network



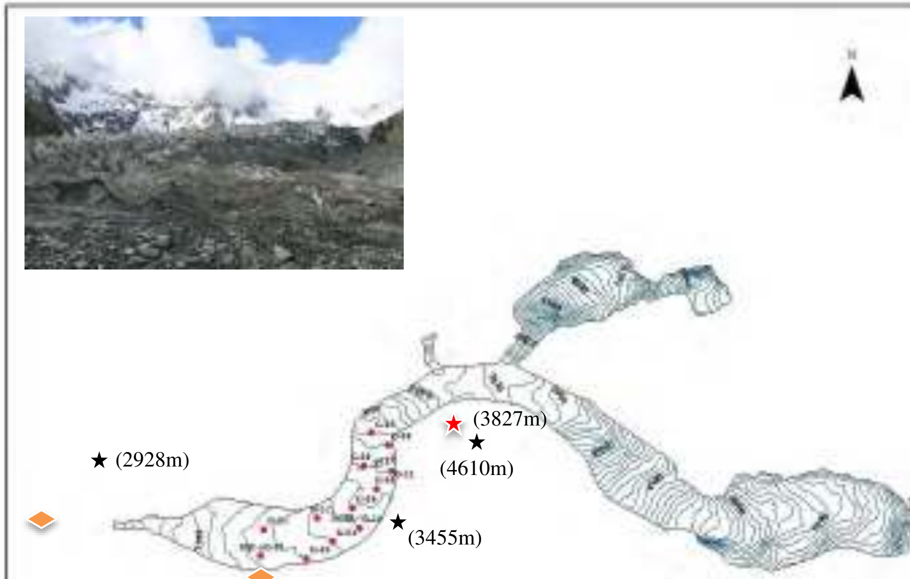
Discharge measurement ★ AWS ★ Rain gauge ● Ablation Stakes ■ Snow pit ■ Lake level gauge

Sachen Glacier (Astore)



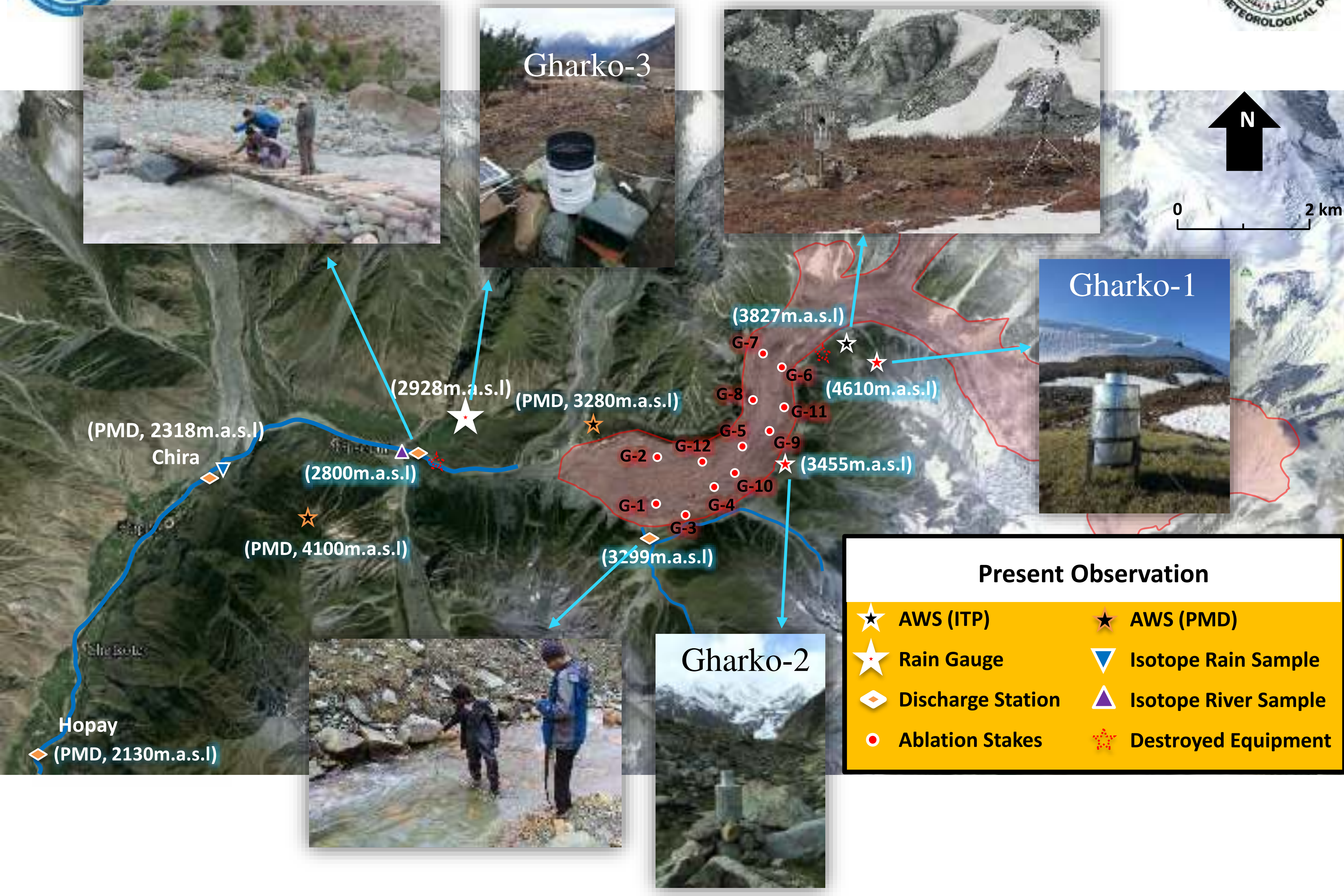


Barpu Glacier (Hunza)

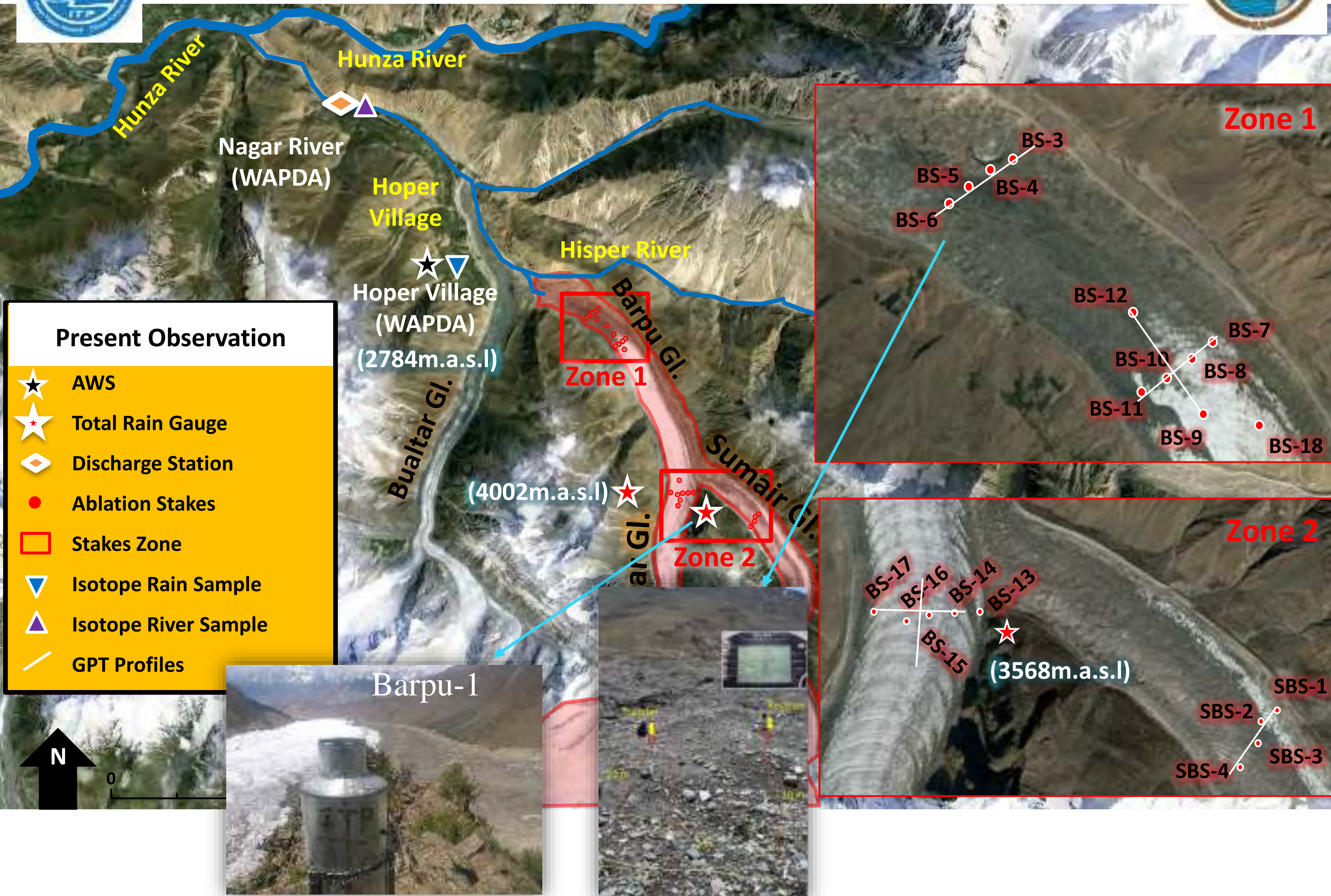


Gharko Glacier (Gilgit)

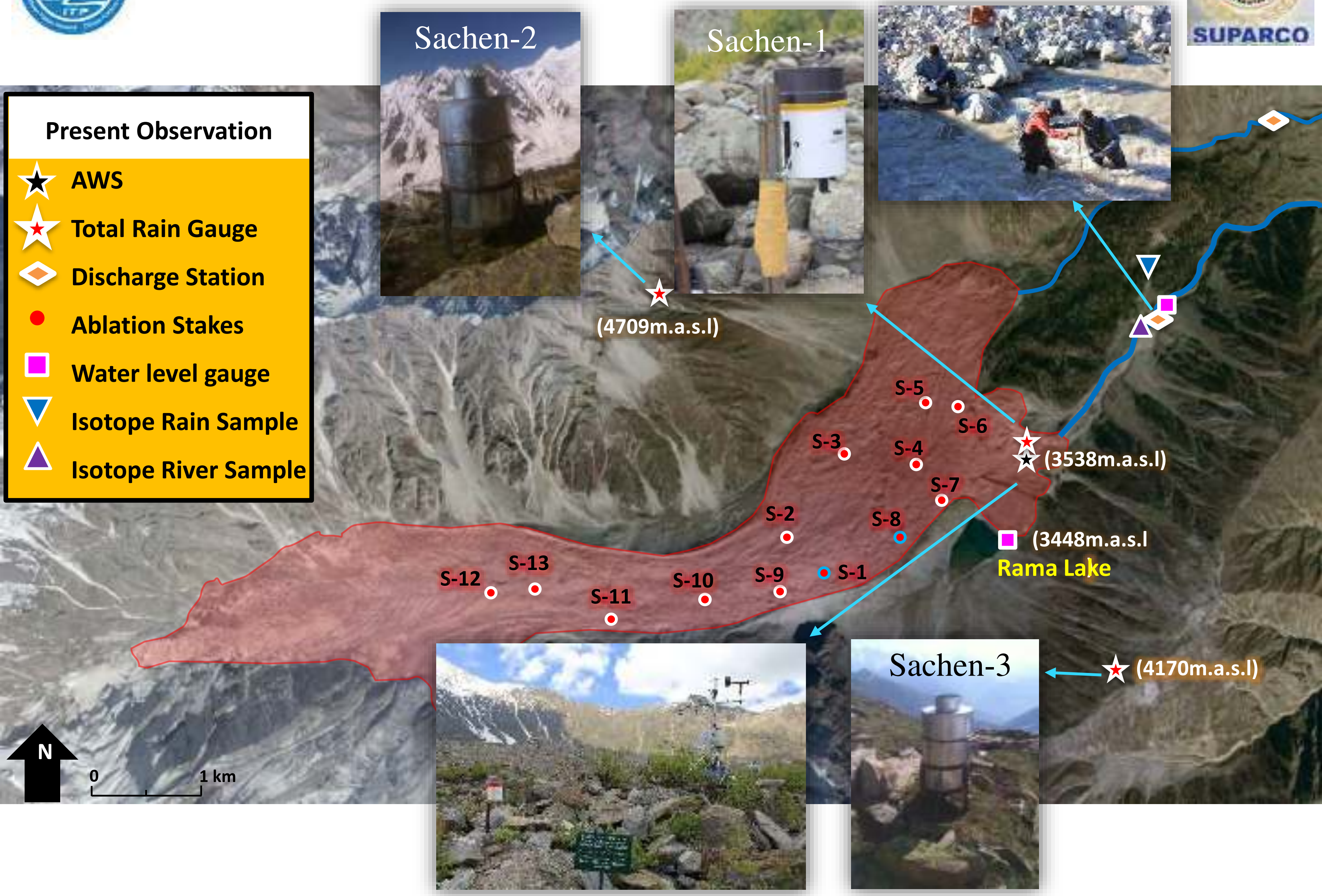
Gharko Glacier Monitoring – ITPCAS & PMD



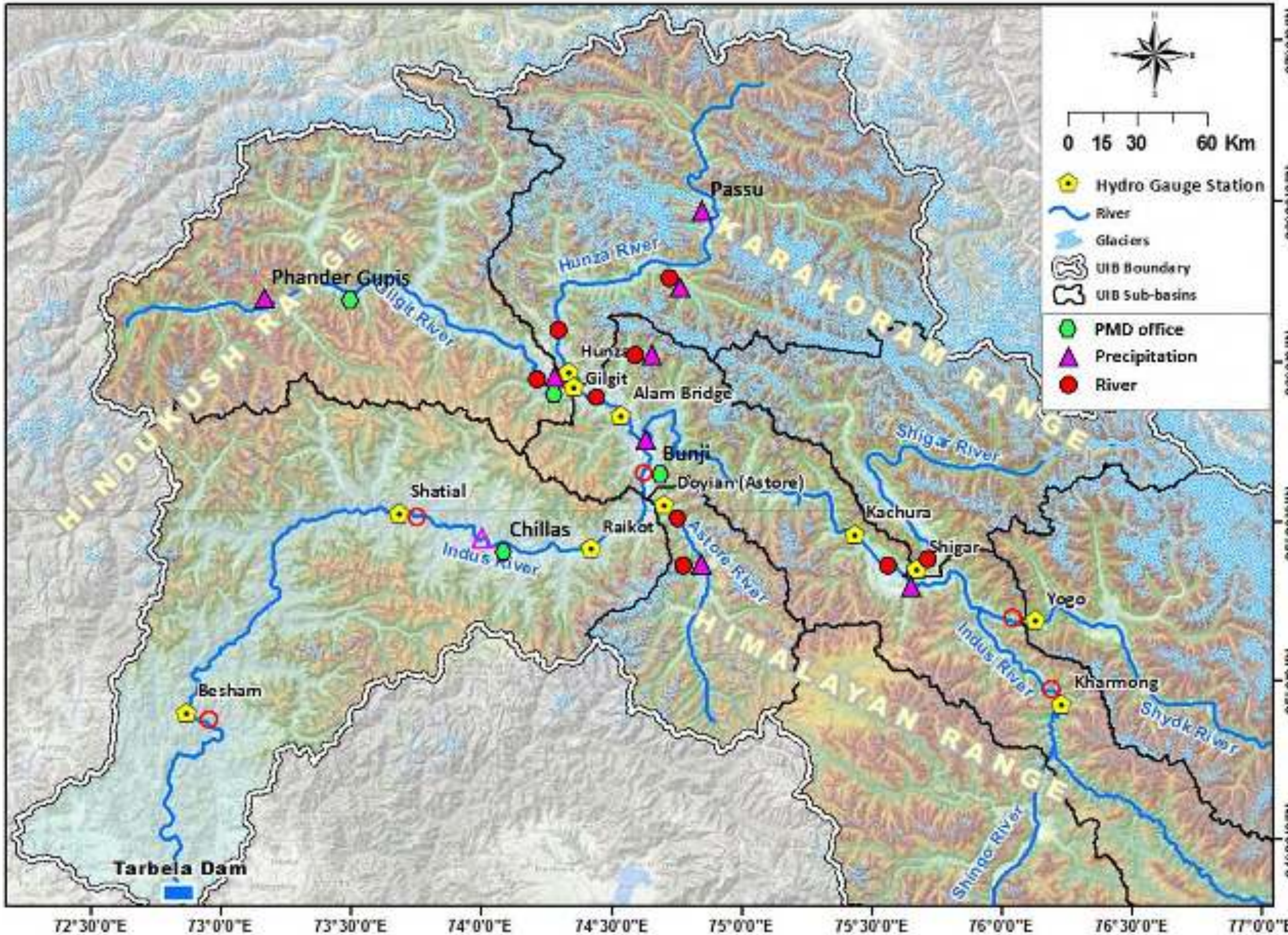
Barpu Glacier Monitoring – ITPCAS & WAPDA



Sachen Glacier Monitoring – ITPCAS & SUPARCO

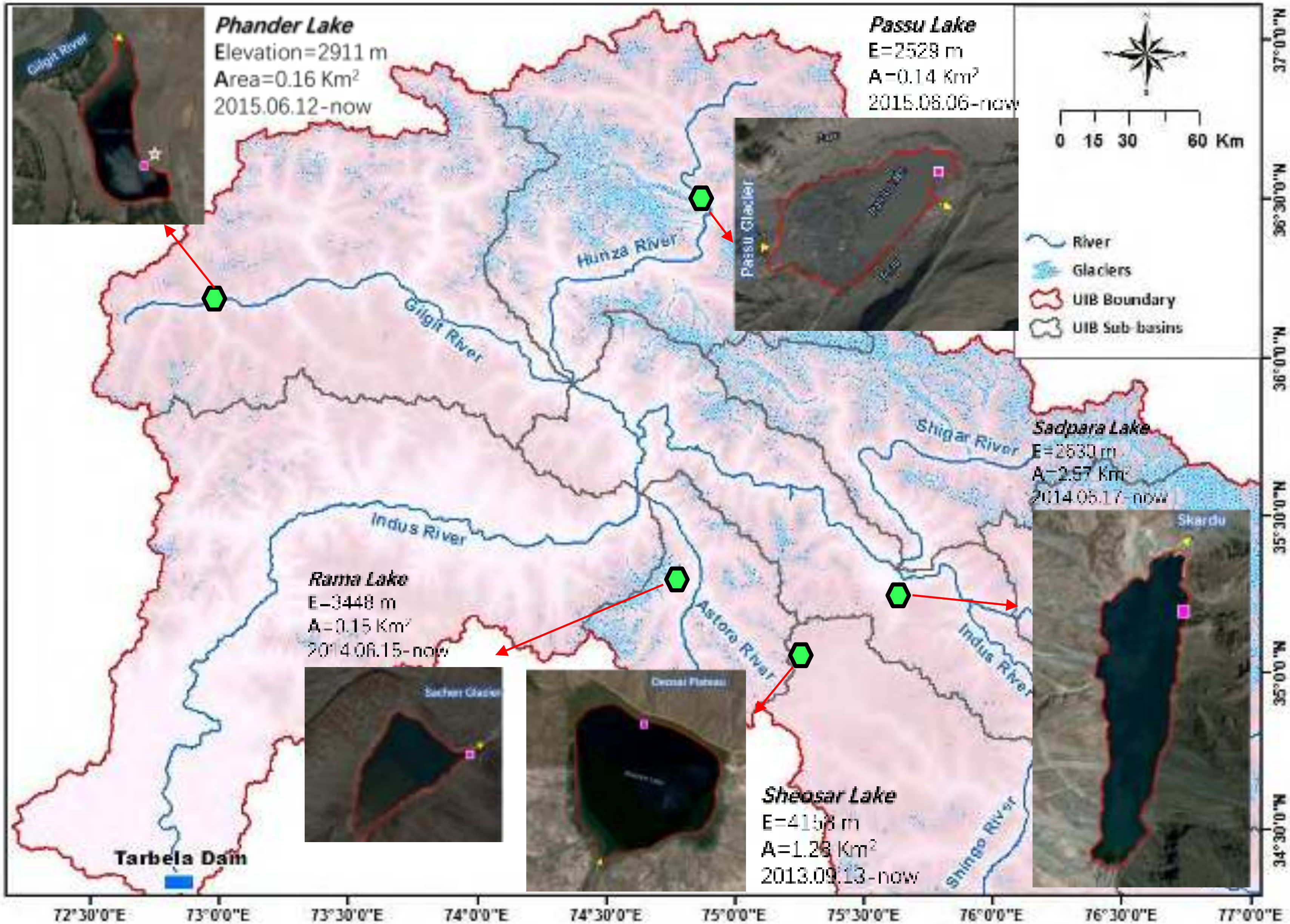


Isotope Sampling in UIB



SUPARCO

Lake Water Level Observation in UIB



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1）Glacio-hydrology

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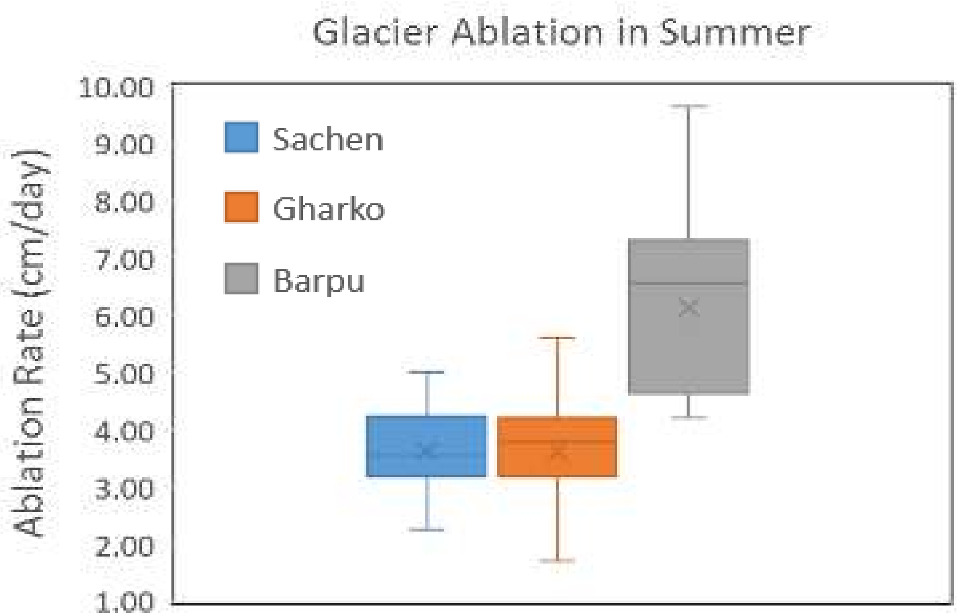
Glacier Ablation – Ablation Rate in Summer



	Ablation Rate	
	Correlation	Sig.
Elevation	-0.379	0.051
Debris Depth	-0.562	0.002

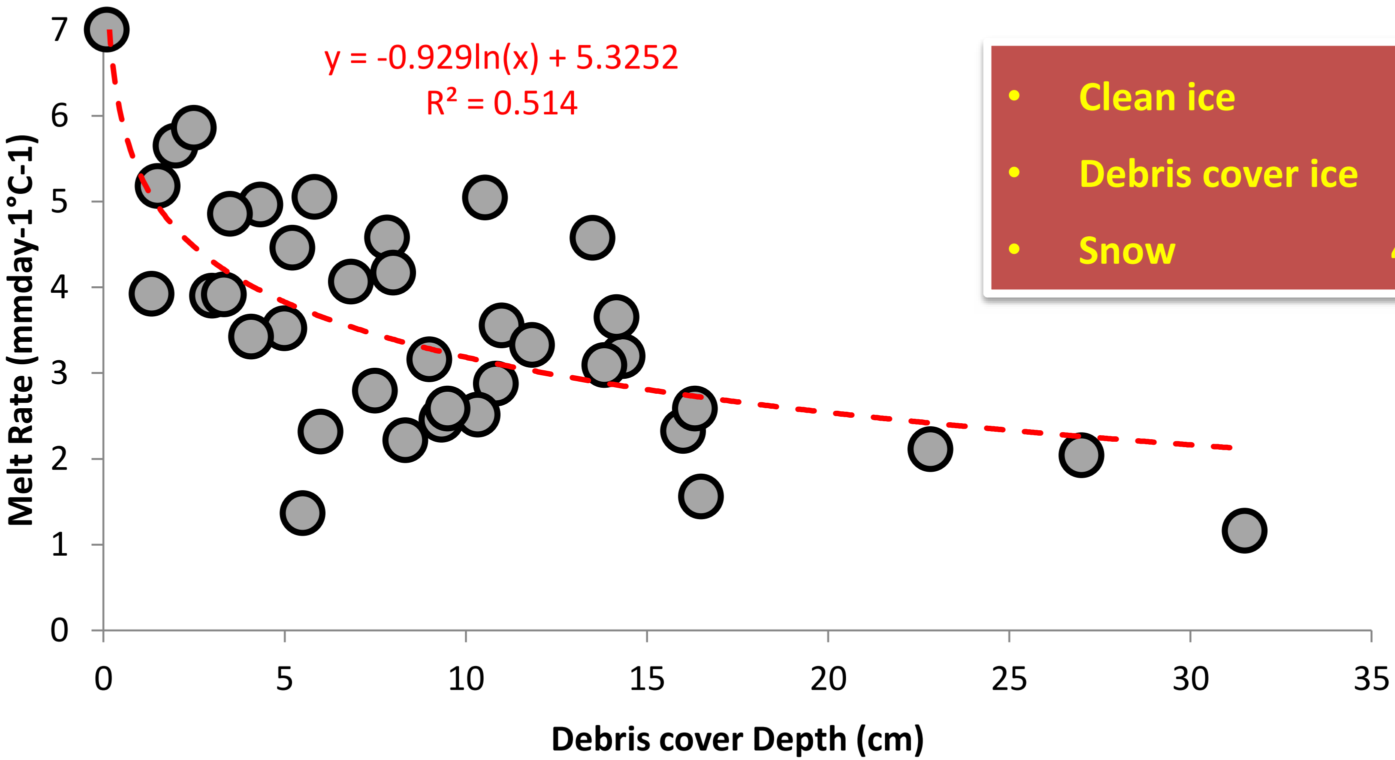
- Ablation Rate in Summer: Barpu > Gharko ≈ Sachen
- Ablation Rate has significantly negative correlation with debris depth, the negative correlation with elevation was not significant.

Glacier Ablation - Degree Day Melt Factor-Debris affect

Impact of Debris over Glacier Ablation

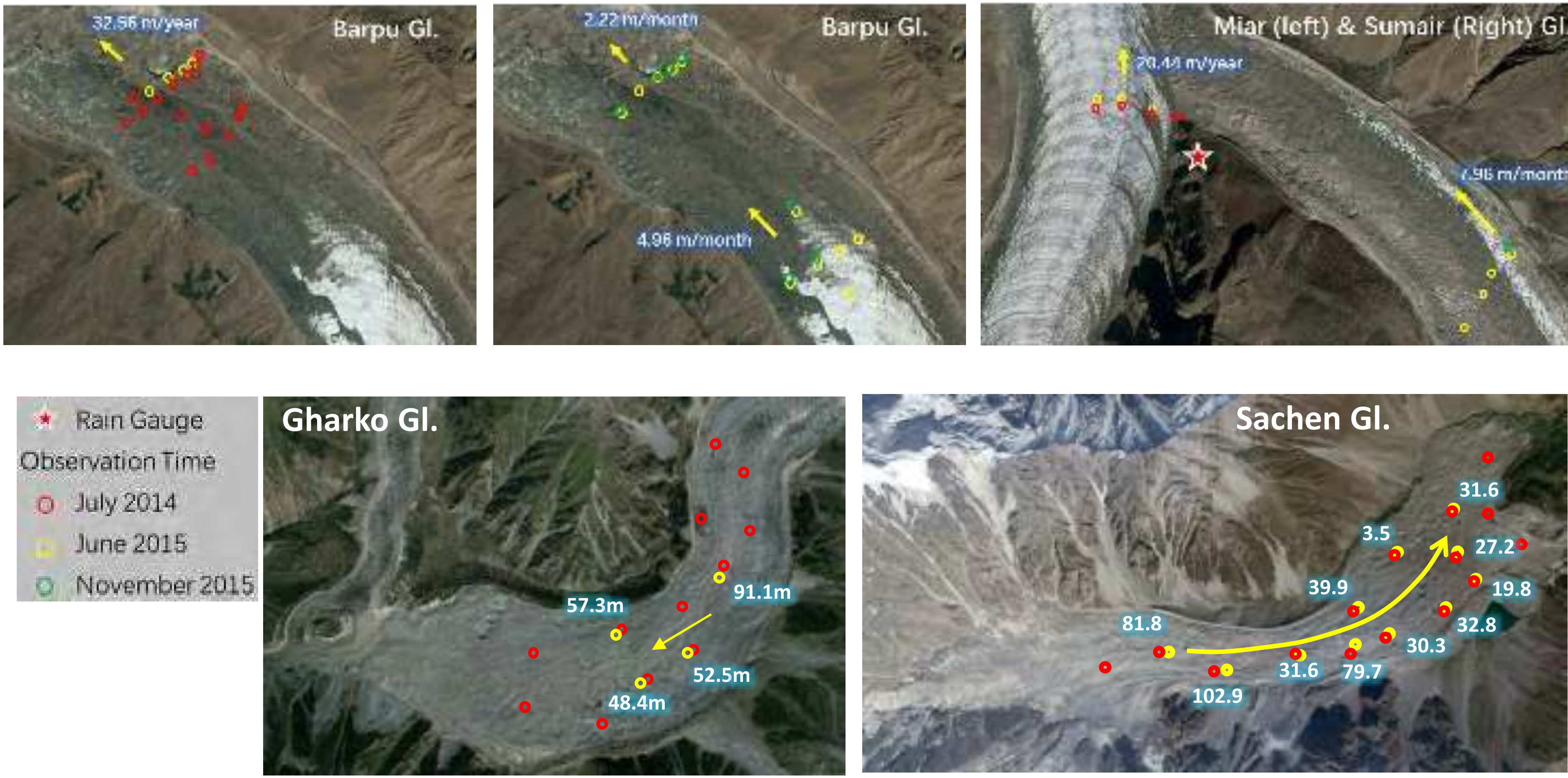
$$a = \frac{A_b}{\Sigma_{nday}\,(T_a - T_0)'}$$

Where A_b is the total ablation (mm)
T_a is the mean daily air temperature
T_0 is the reference temperature
$nday$ is the number of days for the reference period



- Clean ice $7\ mmd^{-1}°C^{-1}$
- Debris cover ice $3.46\ mmd^{-1}°C^{-1}$
- Snow $4.5\ mmd^{-1}°C^{-1}$

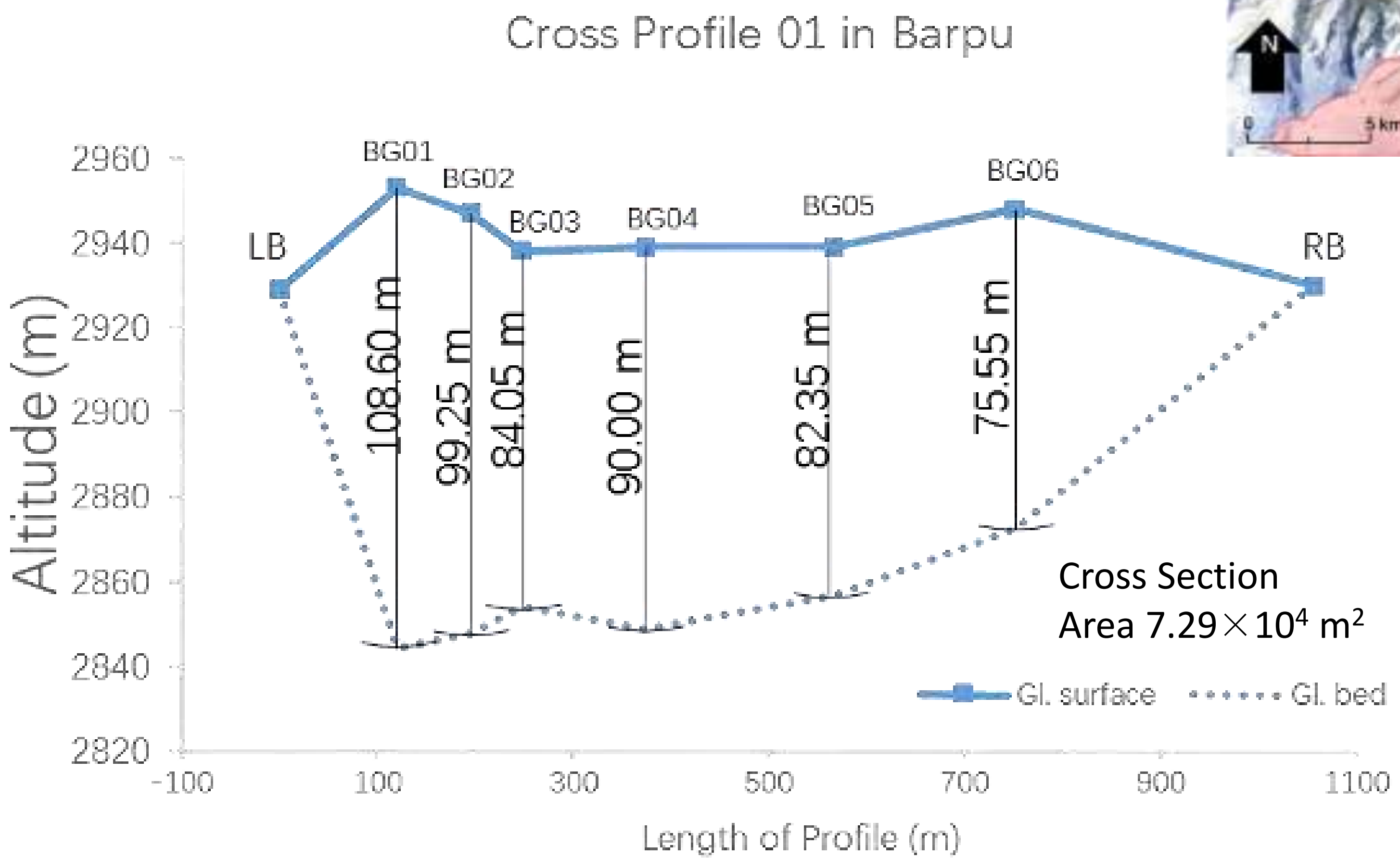
Glacier Surface Movement



Glacier movement rates on the surface in

- Gharko Gl.: 62.3 ± 19.6 m/year
- Sachen Gl.: 43.7 ± 30.5 m/year
- Barpu Gl.: 32.56 ± 3.53 m/year

Glacier Thickness (Barpu Gl.)



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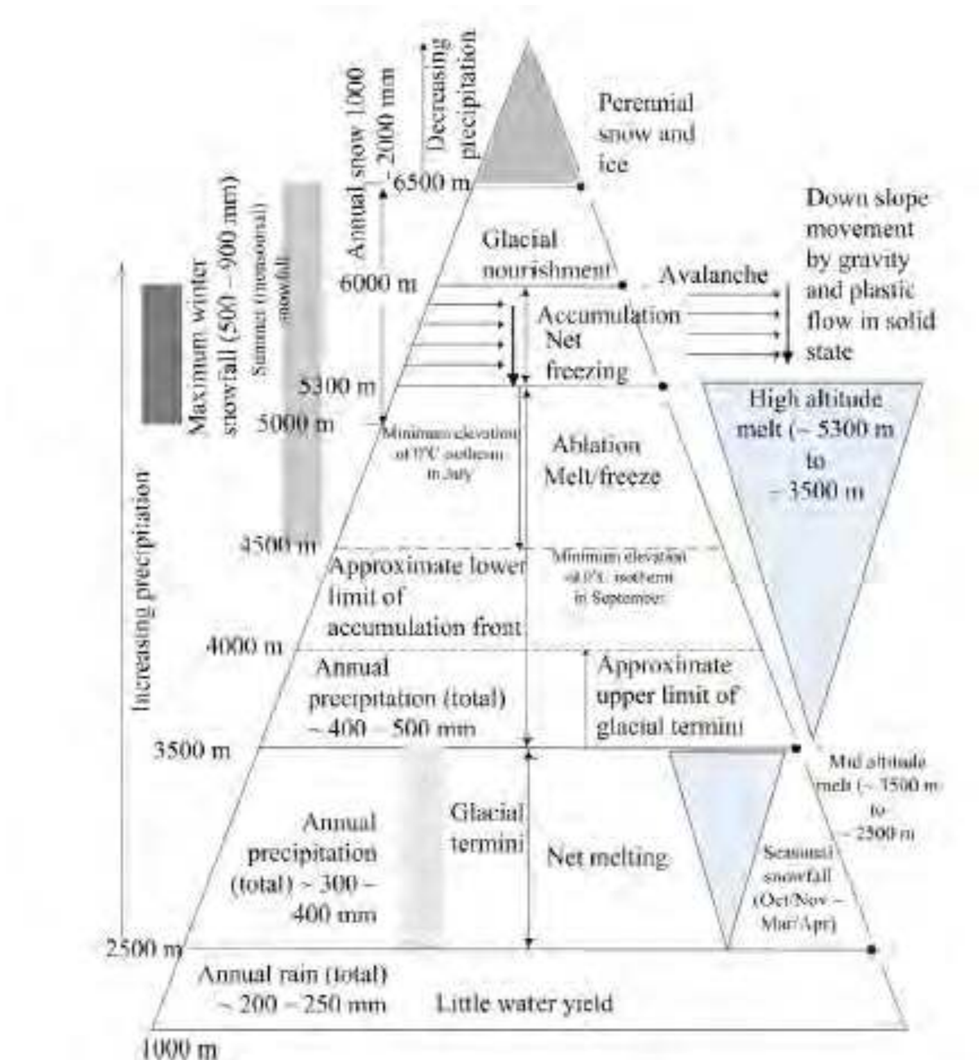
Melt water source of discharge in UIB

Highly generalized diagram
showing origin of two distinct types of melt water in UIB



(Mukhopadhyay and Khan, 2014, JH)

- Melt water from high-altitude catchments in UIB, is a mixture of
  - glacial melts,
  - melts from seasonal snows that fall in the winter and spring prior to the melting season,
  - and summer snowfall that takes place concurrently

Population growth and agriculture have stressed the Indus, which flows the length of Pakistan.

CLIMA TE CHANGE

Indus River waters shrinking

Cooler, cloudier summers slow snowmelt in Himalayas.

Hashmi's data, which are unpublished, come from a network of hydrological stations in Pakistan that span the main stem of the Indus and three of its tributaries. They show that the total water supply fell by 5% between 1962, when the hydrological stations were built, and 2014. "A reduction of 5% over five decades may not seem a lot," says Walter Immerzeel, a hydrologist at Utrecht University in the Netherlands, who led one of the studies that projected an increase in water supply in the Indus (A. F. Lutz *et al. Nature Clim. Change* **4,** 587–592; 2014). "But if the trend persists, there could be devastating implications for water resources." Hashmi's team finds that the river's shrinkage is seasonal, with a decrease in flows between April and August that exceeds a slight increase during the rest of the year. And it reports a temperature drop across the four Pakistani river basins in the summer months — even though the region is getting warmer overall. Because snow- and glacier

Spatial Distribution trends of discharge trend in UIB

1960s-2012

Trend of Discharge

Q - discharge

increase

decrease

Altitude

Variable	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Ann.
Q	UIB-East	0.58	***0.89***	***1.18***	0.80	0.08	-12.94	***-21.37***	-10.53	-1.42	-0.18	0.06	0.16	0.55	1.10	***-14.86***	-0.57	-1.59
	Eastern-Karakoram	0.00	0.00	-0.04	-0.08	***1.79***	***6.46***	5.17	6.81	4.34	***1.31***	**0.24**	0.00	0.07	0.41	**7.08**	***2.05***	***2.43***
	Central-Karakoram	0.32	-0.07	-0.51	**-0.67**	***6.13***	3.85	-1.22	6.30	-7.40	**-4.08**	-1.36	-0.29	-0.35	1.75	6.22	-2.80	0.31
	Kachura	***1.04***	***1.40***	***1.19***	0.43	***6.06***	**12.88**	14.75	***19.45***	**14.27**	***3.69***	***1.14***	***1.13***	***1.12***	***2.67***	***19.20***	***6.12***	***7.19***
	UIB-Central	0.35	0.21	-0.19	-0.43	***9.99***	20.49	13.74	**20.73**	-4.95	-2.15	-0.80	-0.29	-0.30	**2.76**	17.69	-2.84	3.30
	Western-Karakoram	0.04	0.00	0.00	0.00	0.29	**-3.75**	***-12.69***	***-13.75***	**-2.14**	-0.24	0.18	0.20	0.13	0.24	***-10.23***	-0.59	***-2.55***
	Karakoram	0.28	-0.20	-0.60	0.33	9.67	24.33	8.29	8.13	-7.57	-2.18	-0.59	0.63	-0.15	**4.17**	24.39	-4.36	6.44
	Hindukush	0.00	0.05	0.04	0.19	***3.31***	-1.00	-0.85	0.11	0.64	0.23	0.15	0.13	0.04	***1.25***	0.24	0.31	0.48
	UIB-WU	***0.58***	***0.60***	**0.33**	0.51	3.55	-1.86	**-12.74**	***-12.50***	0.68	1.48	***1.02***	**0.71**	***0.48***	1.30	**-6.83**	1.22	-0.95
	Astore	0.28	0.24	***0.32***	***0.97***	***3.52***	1.29	-0.62	0.54	0.16	0.28	0.32	0.23	0.31	***1.63***	0.43	0.28	**0.76**
	Partab_Bridge	***1.01***	0.49	0.44	***1.93***	***18.03***	13.07	12.89	-8.37	9.74	***3.84***	***2.61***	1.63	***1.74***	***6.84***	7.05	**4.93**	**4.72**
	UIB-WL	***1.94***	***1.96***	***3.49***	0.17	2.89	-12.90	-25.95	-12.06	-1.35	1.57	**1.94**	***2.35***	***1.92***	1.93	-13.82	0.48	-2.63
	UIB-WL-Partab	***1.58***	***1.87***	***2.11***	-0.82	-0.30	***-22.26***	-16.35	-17.07	0.02	-2.20	0.23	***1.18***	***1.32***	0.34	-22.10	-0.99	-5.40
	UIB_West	***2.02***	***2.01***	***2.73***	1.12	8.00	***-19.88***	***-32.88***	***-23.24***	-5.13	1.95	***2.59***	***2.40***	***2.18***	3.99	***-25.21***	0.93	-4.03
	Himalaya	***3.23***	***3.91***	***4.73***	2.33	-0.33	-32.29	***-69.33***	-17.55	-4.61	-0.05	**3.40**	2.05	***3.37***	6.86	-40.09	-0.72	-6.13
	UIB	***3.00***	***3.33***	***3.53***	0.62	***12.97***	-8.84	-13.31	-3.24	8.19	***4.03***	***3.92***	***3.04***	***3.04***	***5.00***	-6.15	**5.14**	2.23

(Hasson et al., 2015)

- Winter discharge features an increasing trend, while for the rest of seasons and on an annual time scale, sites mostly exhibit a mixed response.
- Shift during the seasonal transitional month of June and within the high flow months July-September
  - long term trend: eastern-, central- and whole Karakoram, UIB-Central, Indus at Kachura, Indus at Partab Bridge and Astore regions is increasing while rest of regions is decreasing
  - May attribute to a multi-decadal variability of climatic processes over the region, which is driven by NAO and ENSO

Contribution of snow/ice to runoff -Improvement of Lutz et al. 2014 work

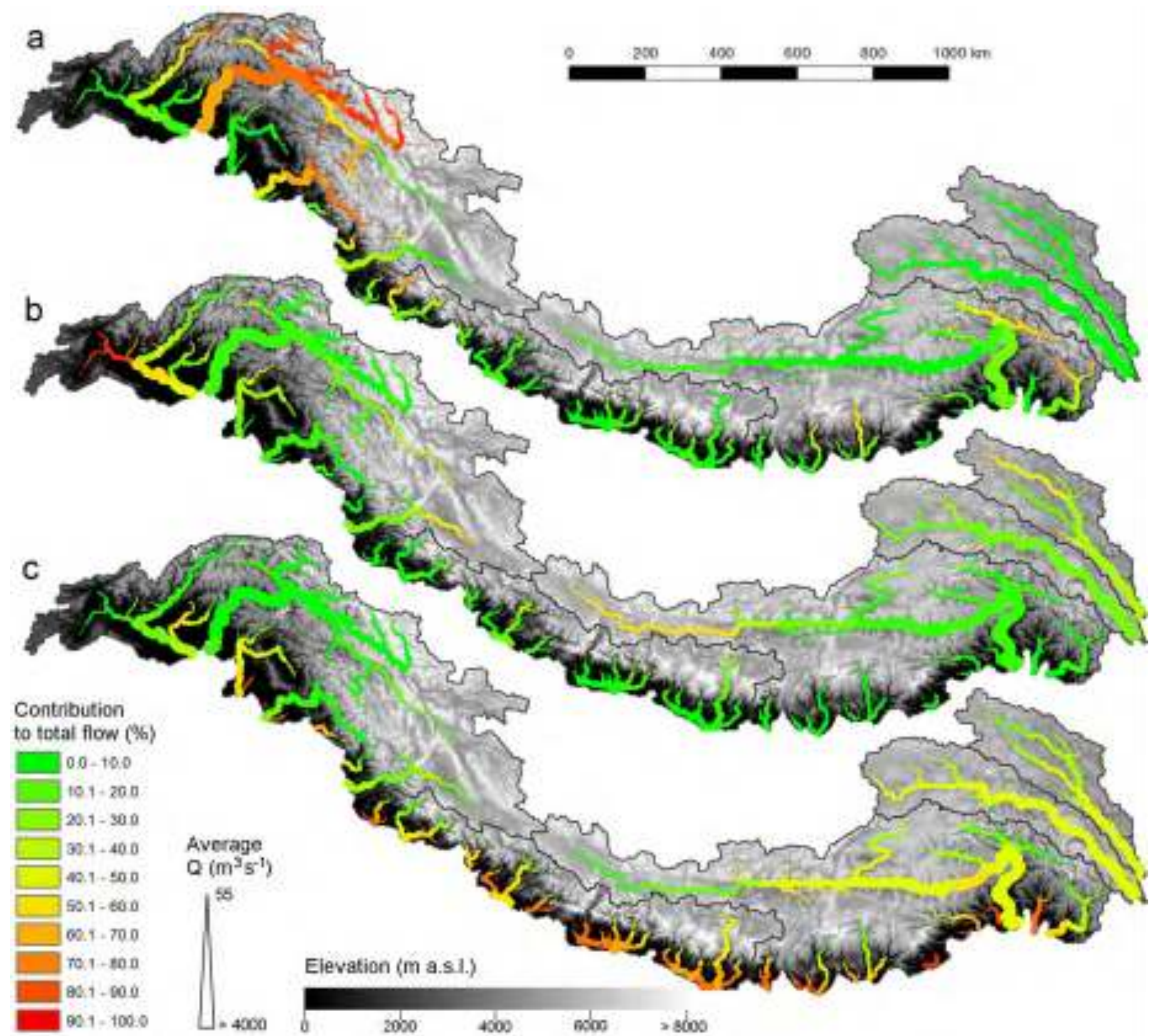
- Lutz, A. F., W. W. Immerzeel, A. B. Shrestha, and M. F. P. Bierkens, 2014: Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. Nature Clim. Change, 4, 587–592.
- Extend the timeline to 2100
- Improve glacier/groundwater module
- Improve forcing data: reference
- Improve forcing data: future
  - Lutz, A. F., H. W. ter Maat, H. Biemans, A. B. Shrestha, P. Wester, and W. W. Immerzeel, 2016: Selecting representative climate models for climate change impact studies: an advanced envelope-based selection approach. *International Journal of Climatology*, ***n/a-n/a.***
- Consider extreme events

Contribution to total flow by glacier melt (a),

snow melt
(b)

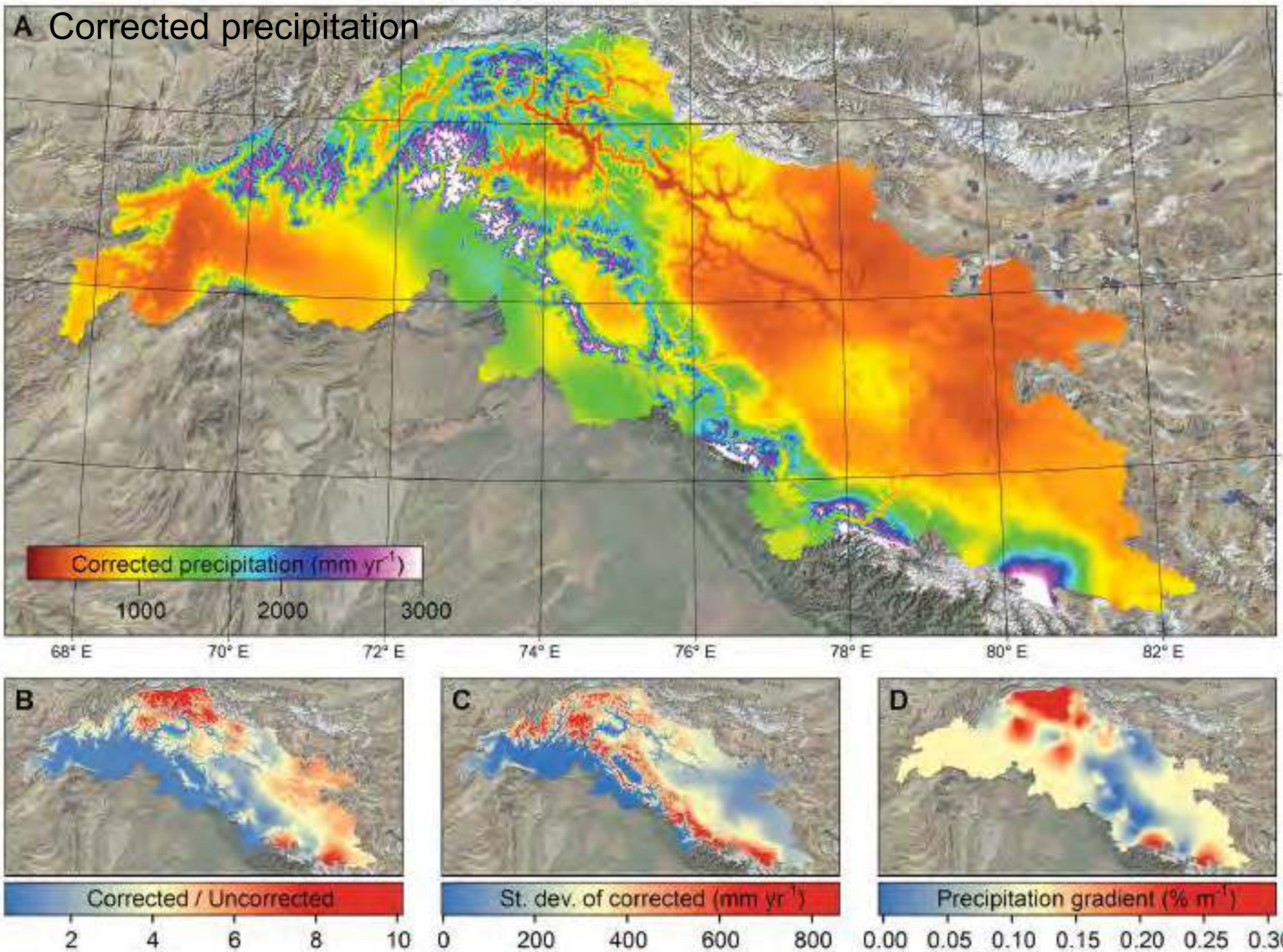
and rainfall-runoff
(c) for major streams during the reference period (1998-2007).

Line thickness indicates the average discharge during the reference period [Lutz et al., 2014]

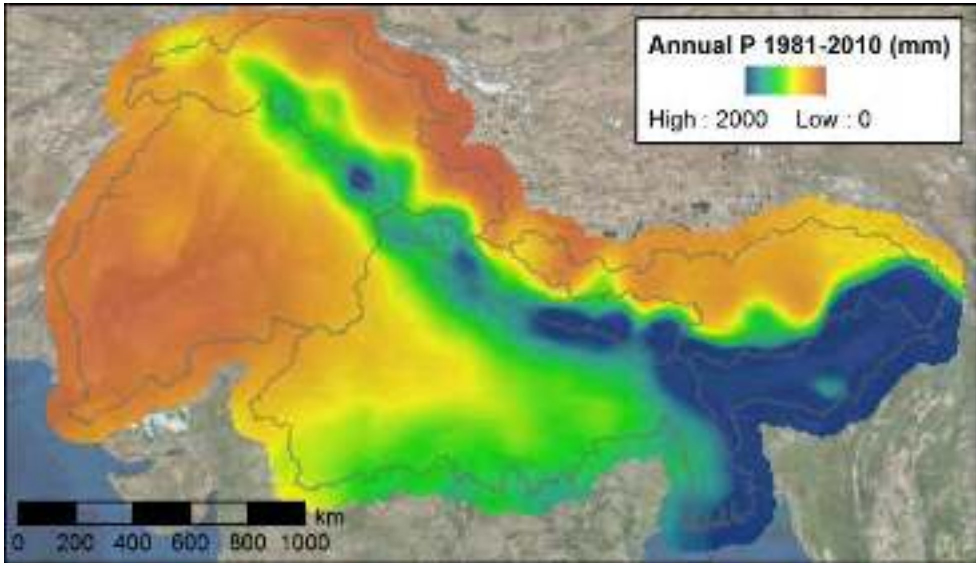


Reconciling high-altitude precipitation in the upper Indus basin with glacier mass balances and runoff

- Immerzeel, W. W., N. Wanders, A. F. Lutz, J. M. Shea, and M. F. P. Bierkens, 2015: Reconciling high-altitude precipitation in the upper Indus basin with glacier mass balances and runoff. Hydrol. Earth Syst. Sci., 19, 4673-4687.
- Lack of high altitude precipitation observation
- Reanalysis products have high bias – gap in water balance
- Use of RS based glacier mass balance used to inversely infer the precipitation data
- Valadation with observed runoff data shows the improved ppt data closes the water balance better

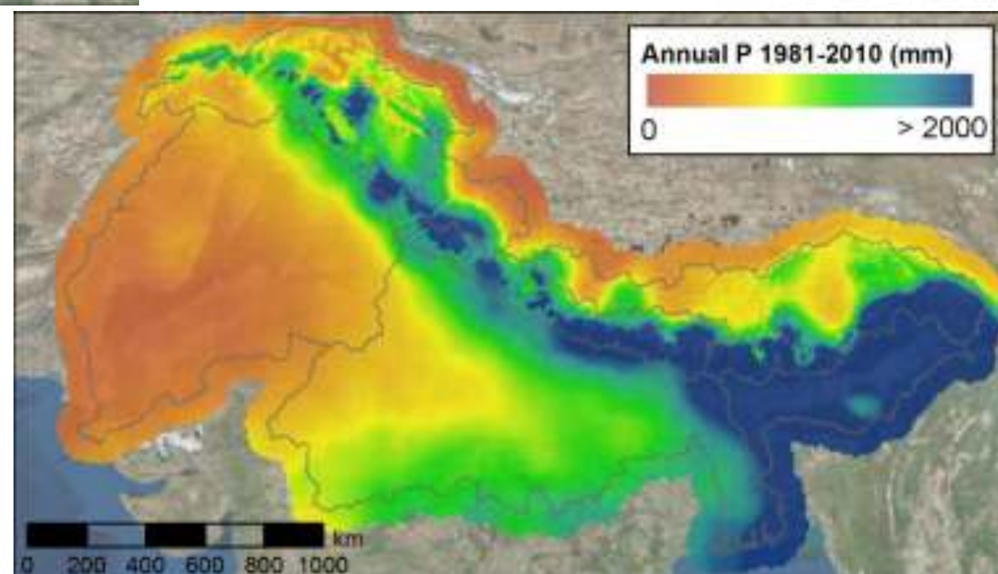

A Corrected precipitation
Corrected precipitation (mm yr⁻¹)
1000
2000
3000
36° N
34° N
32° N
68° E
70° E
72° E
74° E
76° E
78° E
80° E
82° E
B
Corrected / Uncorrected
2
4
6
8
10
C
St. dev. of corrected (mm yr⁻¹)
0
200
400
600
800
D
Precipitation gradient (% m⁻¹)
0.00
0.05
0.10
0.15
0.20
0.25
0.30

Extending to IGB basins



Uncorrected

Corrected



Future proposal

A. High altitude hydrology: precipitation
B. Integrate observation network
C. Collaborative model simulation

D. Learning from existing programmes, invitation of experts:
   - PMD WAPDA
   - EvK2-CNR
   - ICIMOD
   - NASA: real time precipitation data-Precipitation Measuring Mission (PMM)
   - Alpine experiences (SLF, ANETZ)
   - etc.

E. Responsibilities for programme- and schedule-design