

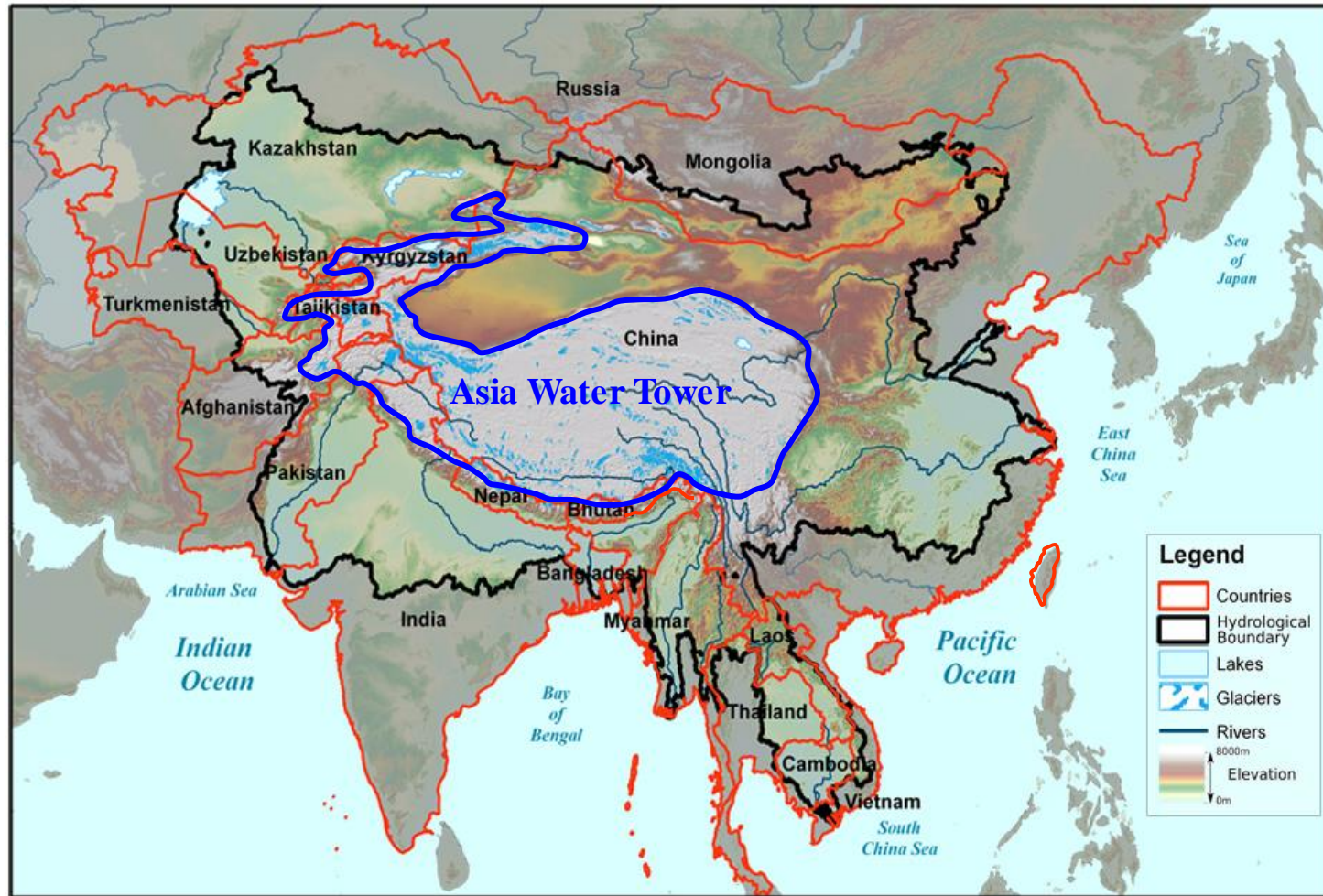
Heterogeneity of glacier changes in UIB region

-Where, When is the Karakoram Anomaly?

Yinsheng Zhang , Xiaojuan Zou , Haifeng Gao

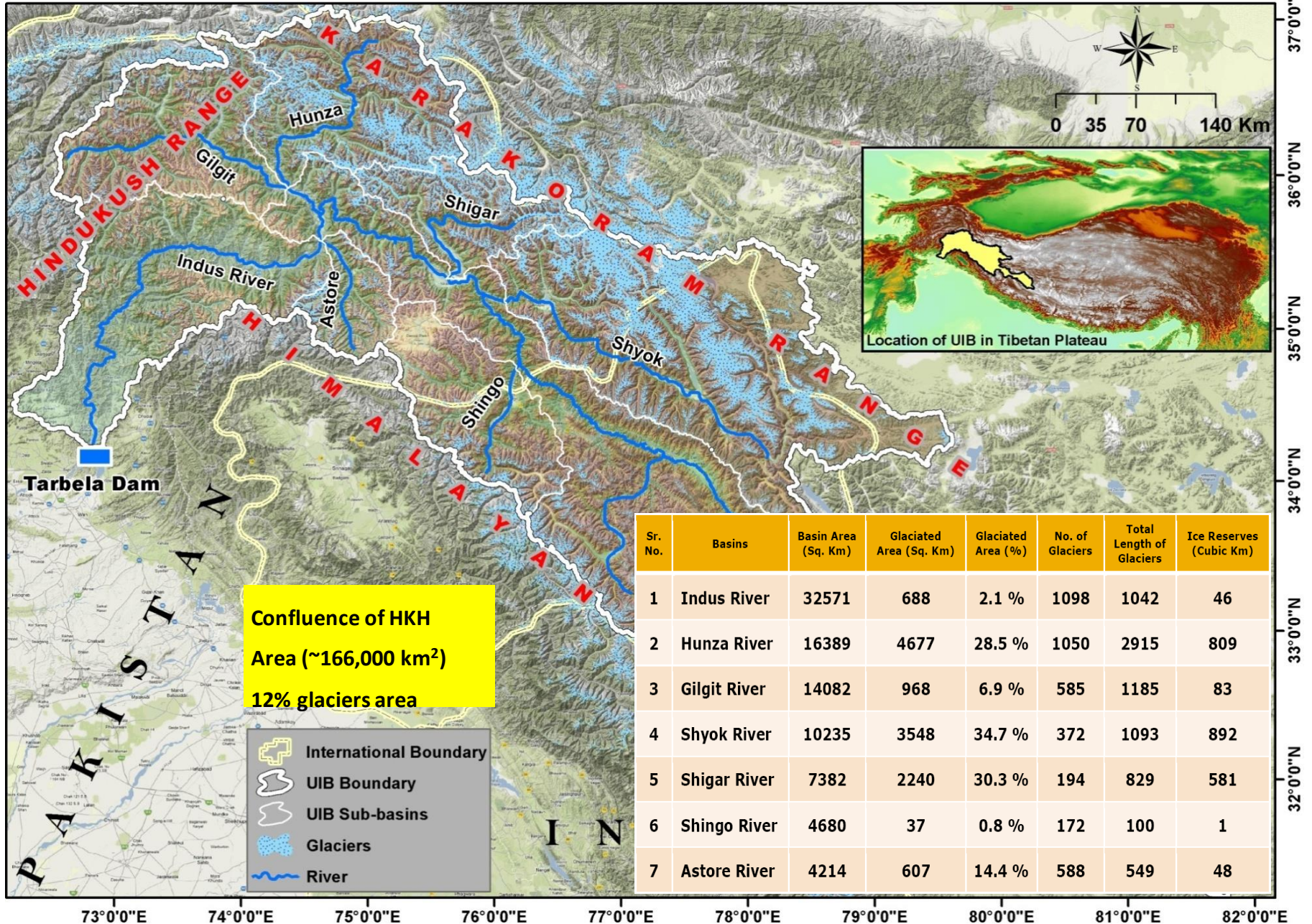
Institute of Tibetan Plateau Research
Chinese Academy of Sciences

TPE – Water Tower of the Asia Region



➤ **Upper Indus River Basin (UIB) - Water Tower of Pakistan**

Huge amount of Glaciers in Upper Indus Basin (UIB)



—Karakoram Anomaly (Hewitt, 2005; Gardelle et al., 2012)

Mountain Research and Development Vol 25 No 4 Nov 2005: 332–340

Kenneth Hewitt

The Karakoram Anomaly? Glacier Expansion and the 'Elevation Effect,' Karakoram Himalaya

LETTERS

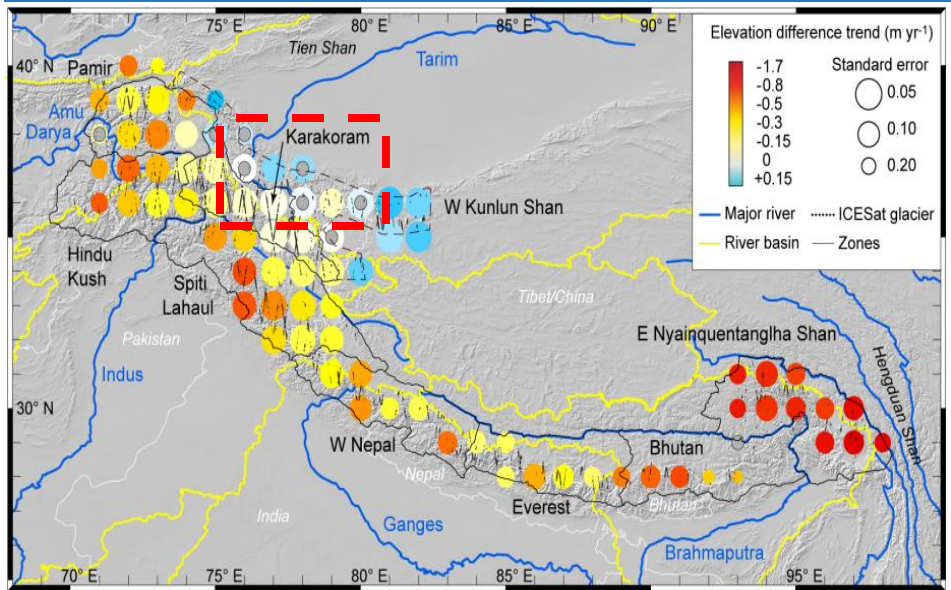
PUBLISHED ONLINE: 15 APRIL 2012 | DOI: 10.1038/NNGEO1450



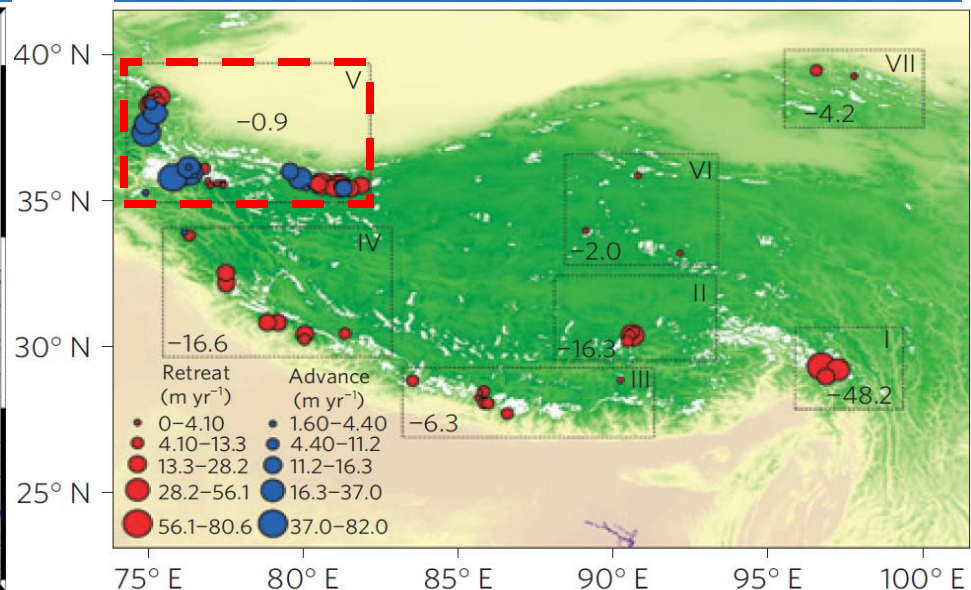
Slight mass gain of Karakoram glaciers in the early twenty-first century

Julie Gardelle^{1*}, Etienne Berthier² and Yves Arnaud³

ICESat-SRTM (Kääb et al., 2015)

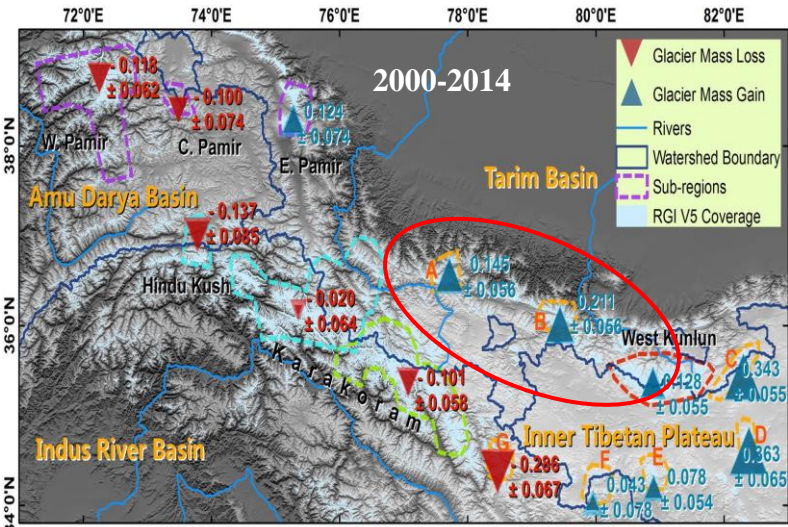


Observation (Yao et al., 2012)

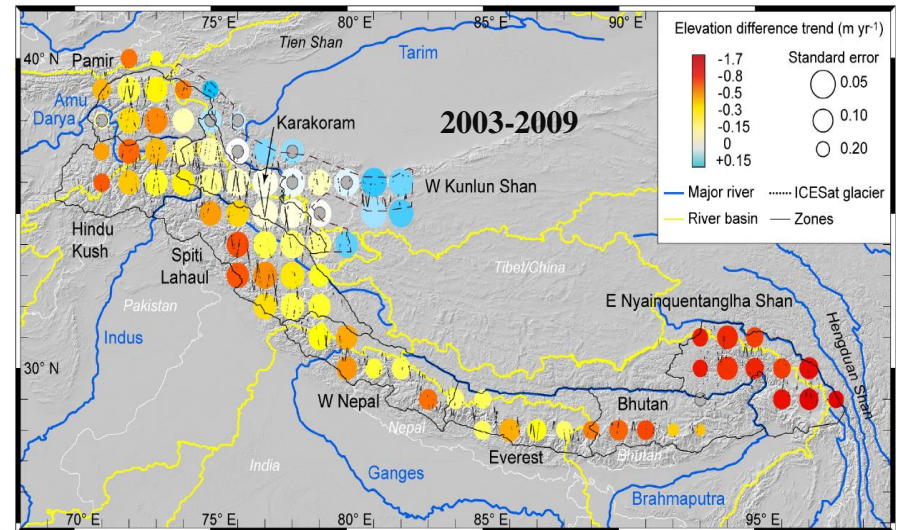


Confusion in the former studies

Ref	Method	Region	Period	Area changes (km ²)
(Hewitt, 2007; 2005)	实测/Landsat	Karakoram	1985-2001	1990s, Centre Karakoram
(Schmidt et al., 2012)	Corona/SPOT/Landsat	Kang Yatze	1969-2010	-13.8
(Kulkarni et al., 2011)	Maps/LISS III	Zanskar	1962-2001	-94
(Bhambri et al., 2013)	Landsat	Shyok	1973-2011	+2.2
(Agarwal et al., 2016)	Landsat	Siachen (Shyok)	1980-2014	-0.5
Ref	Method	Region	Period	Mass balance (m w.e. yr ⁻¹)
(Bolch et al., 2012)	实测/大地测量	KH	1960-2010	Karakoram+
(Zhou et al., 2017)	KH-9/SRTM	Karakoram	1973-2000	-0.09
(Bolch et al., 2017)	KH-9/SRTM/ASTER	Hunza	1973-2009	-0.06
(Fujita et al., 2011)	能量平衡模型	TP	1988-2007	High e'le
(Kumar et al., 2015)	REMO _{glacier} 模型	KH	1989-2008	ELAstable
(Yao et al., 2012)	实测/Landsat/ASTER	TP及周边	2000-2010	Pamir&Karakoram (+0.25)
(Kääb et al., 2012)	SRTM/ICESat	HKKH	2003-2008	Karakoram冰量损失 (-0.10)
(Gardelle et al., 2013)	SRTM/SPOT-5	Karakoram	2000-2011	Pamir & Karakoram (+0.37)
(Neckel et al., 2014)	SRTM/ICESat	TP	2003-2009	Nrth TP (+0.37)
(Brun et al., 2017)	实测/ASTER	HMA	2000-2016	Karakoram (-0.05)
(Lin et al., 2017)	高精度雷达	Karakoram	2000-2014	Karakoram?

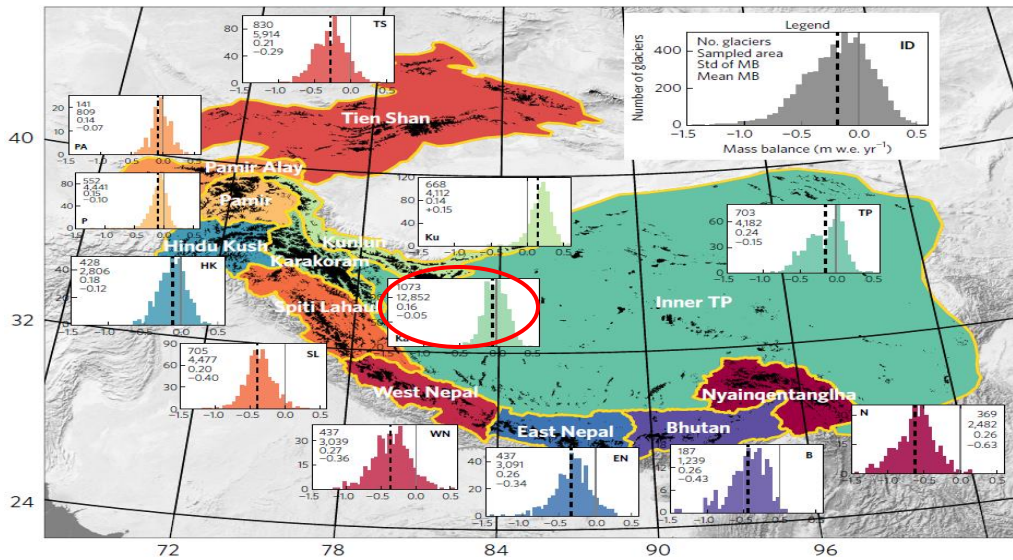


(Lin *et al.*, 2017)

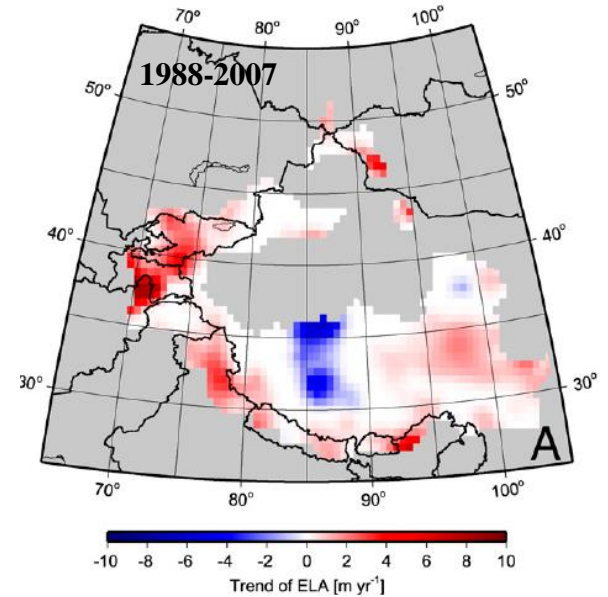


(Kääb *et al.*, 2015)

2000-2016



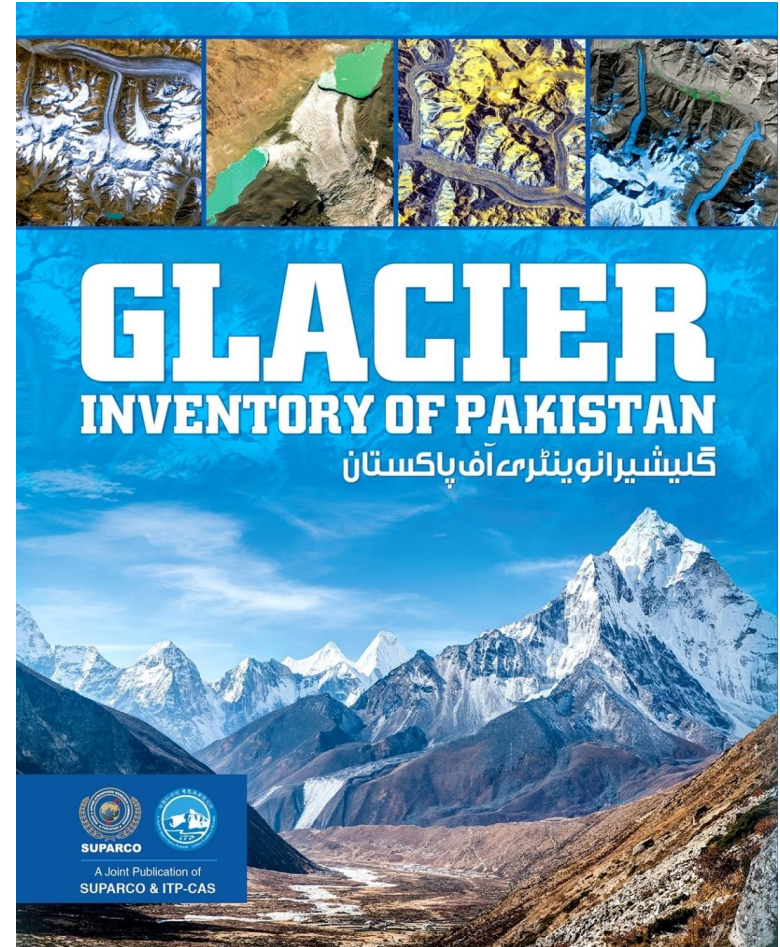
(Brun *et al.* 2017)



(Fujita *et al.*, 2011)

Methods-Data acquisition

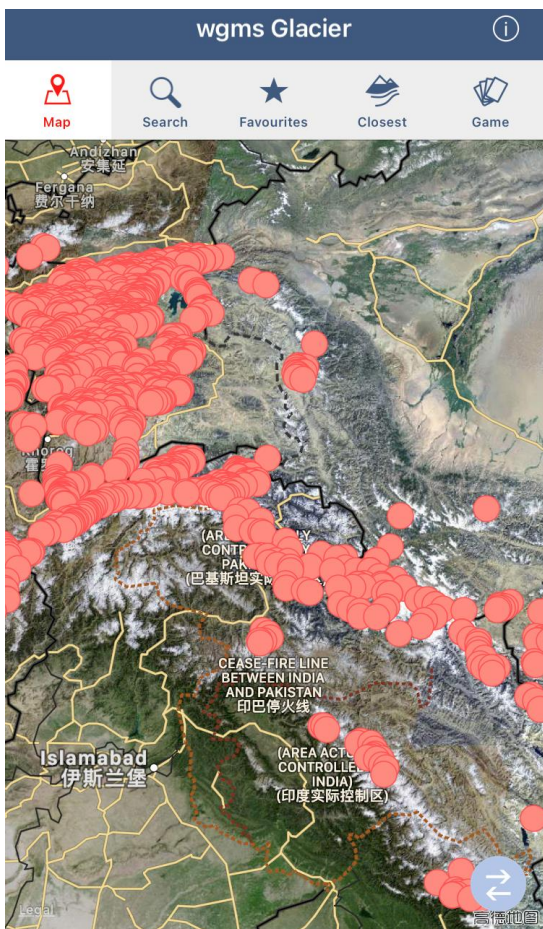
- Glacier outline: Glacier Inventory of Pakistan (Landsat)
- Glacier surface elevation :
 - ICESat (2003-2008), point data, (Kääb et al., 2015)
 - ASTER DEM (2000-2016), dh/dt, (Brun et al., 2017)
- Glacier elevation: SRTM DEM (2000)
- Ice thickness:
 - **Field survey:**
 - **DGPS, 2015-2018**
 - **GPR, 2015-2018**
 - Model calculation: using SRTM DEM data



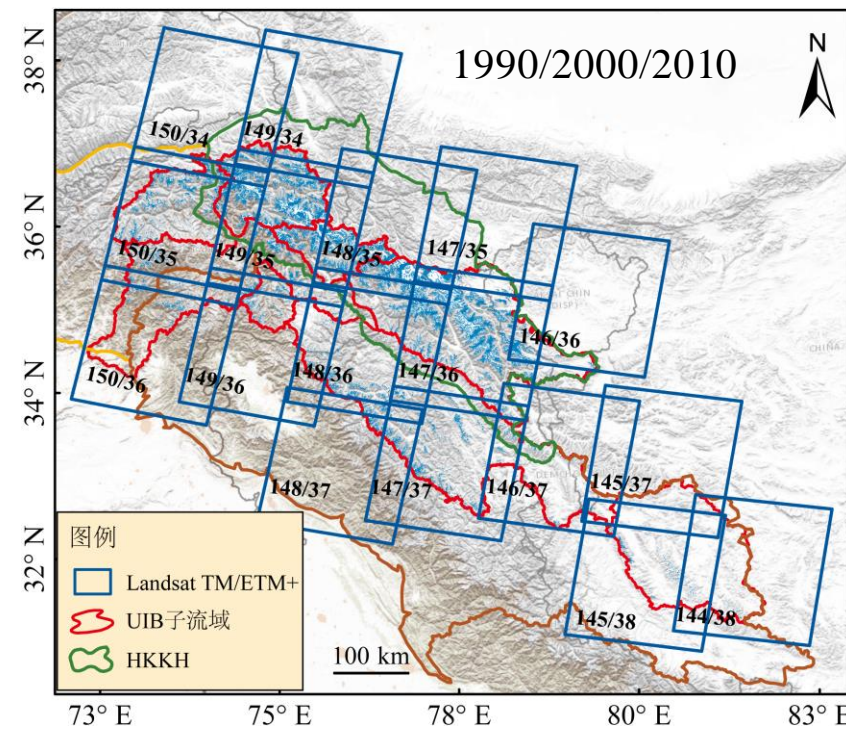
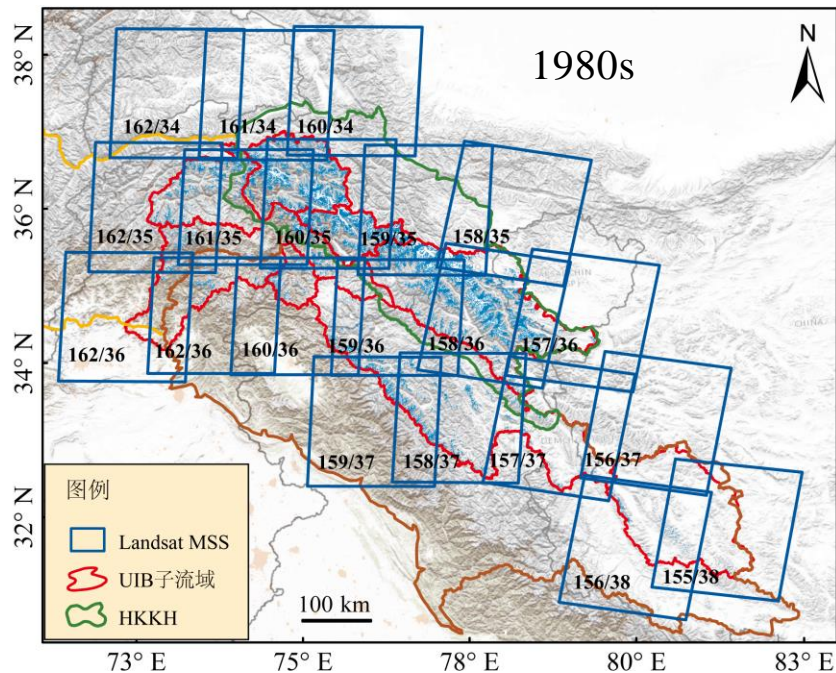
➤ Glacier area

- ❑ 1980s Landsat MSS
- ❑ 1990/2000/2010年
Landsat TM/ETM+

WGMS App 2.0

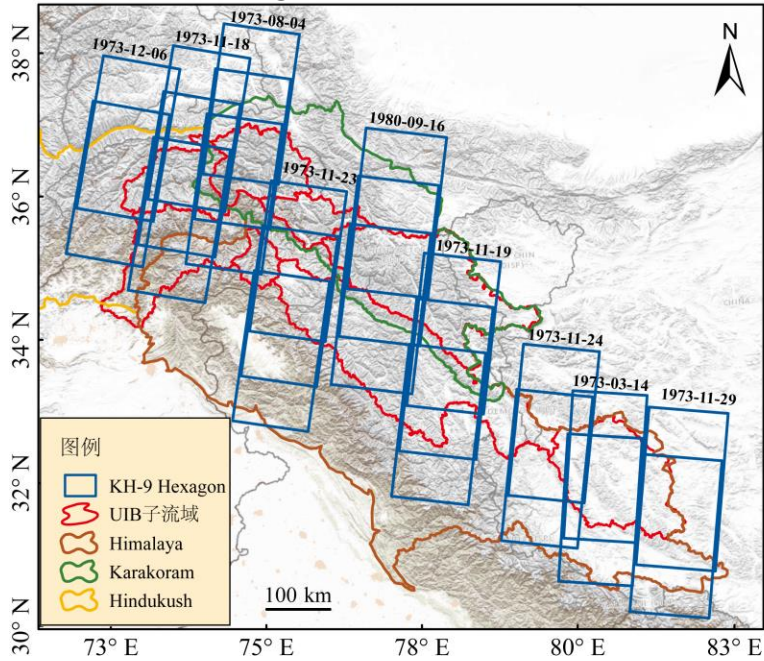


- ❑ WGMS App 2.0
since 1980s



➤ Ice surface changes_1973-2000

KH-9 Hexagon



Glacier surface elevation :

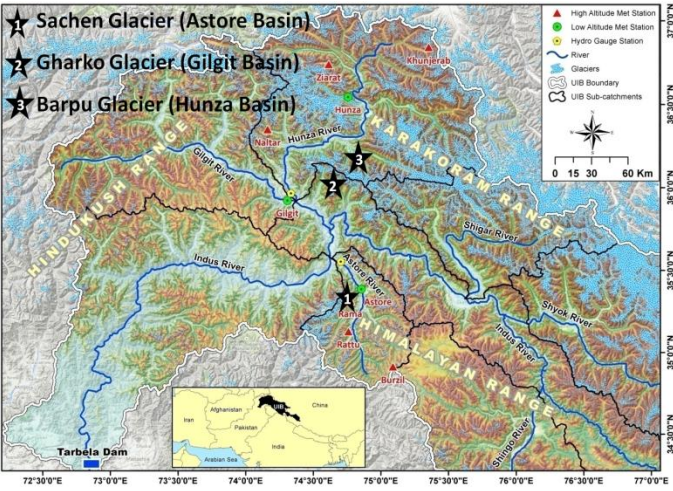
ICESat (2003-2008), point data, (Kääb et al., 2015)

ASTER DEM (2000-2016), dh/dt, (Brun et al., 2017)

$$B_N = \frac{\rho}{s_g} \sum_{i=1}^N \Delta h_i s_i$$

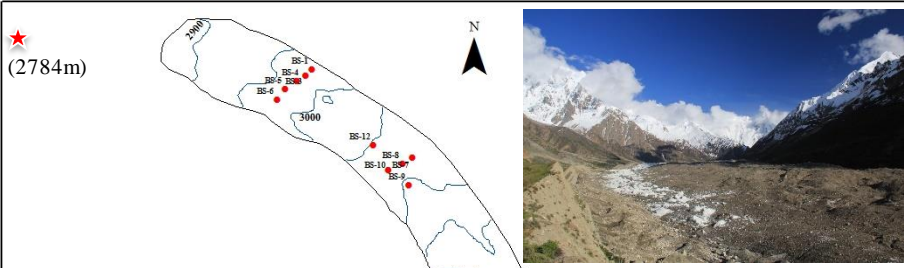
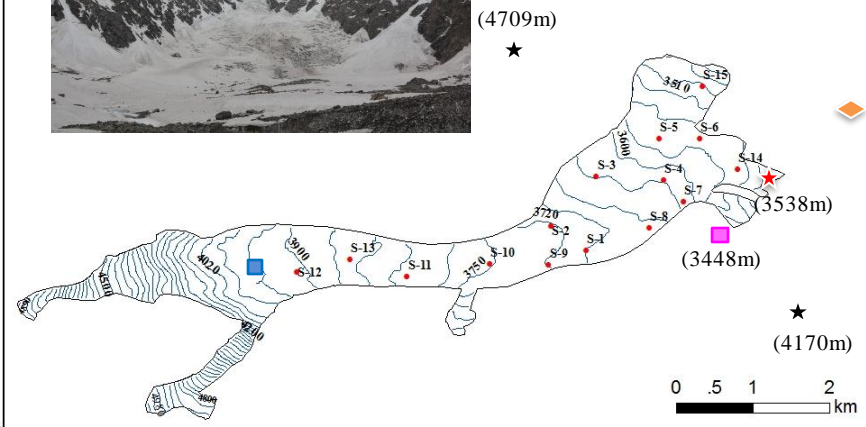
Glacier Mass Balance Observation

Location of observed glaciers

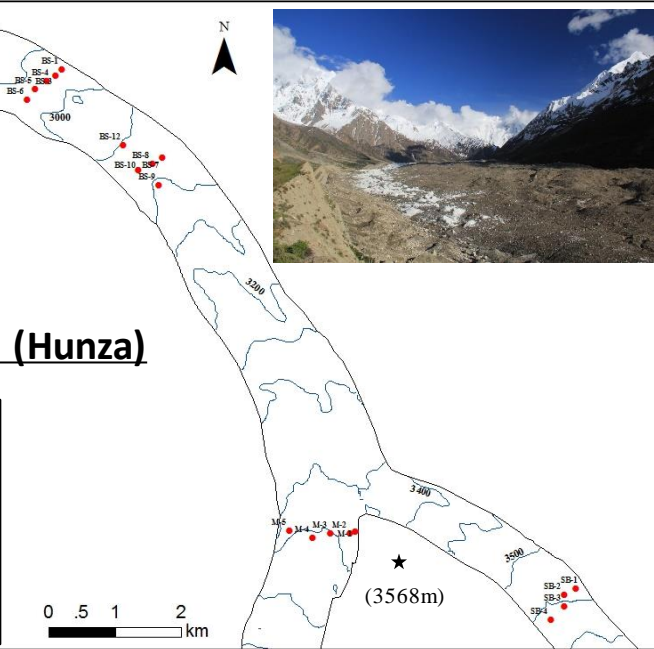
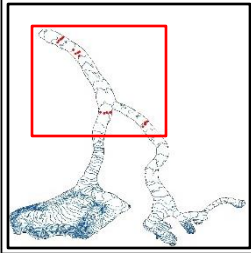


◆ Discharge measurement
 ★ AWS
 ★ Rain gauge
 ● Ablation Stakes
 ■ Snow pit
 ■ Lake level gauge

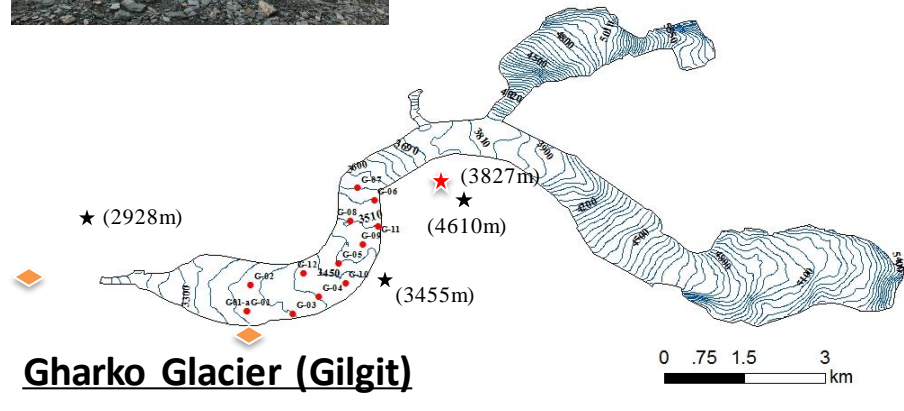
Sachen Glacier (Astore)



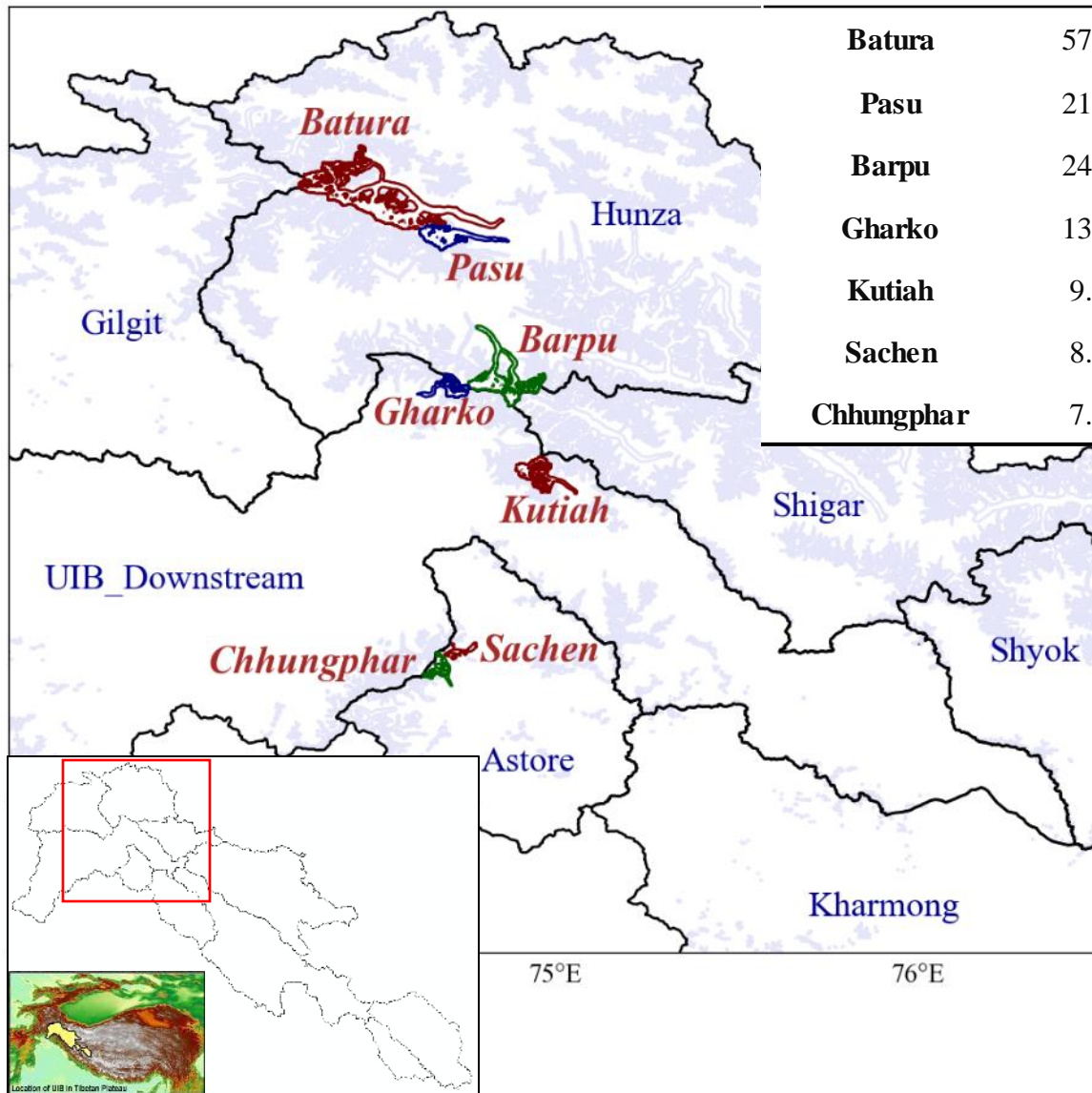
Barpu Glacier (Hunza)



Gharko Glacier (Gilgit)



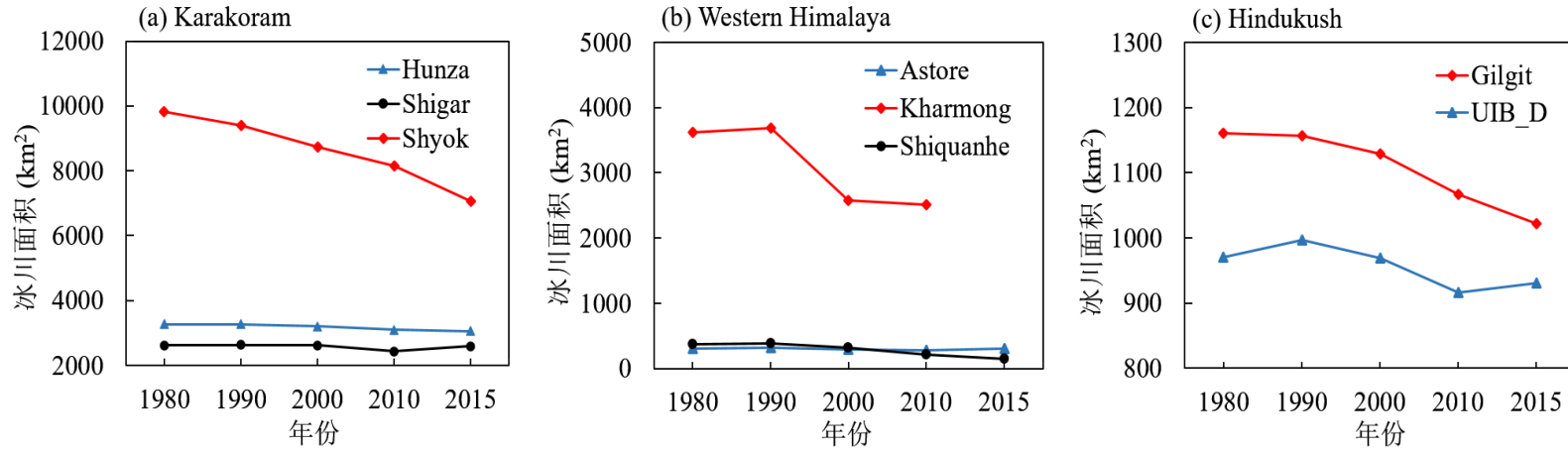
Field Observation-map



Glacier	Length (km)	Area (km ²)	Elevation Range (m)	GPR Profile /Points
Batura	57.3	243.5	2508-7771	3 /24
Pasu	21.5	62.2	2575-7569	3 /10
Barpu	24.5	90.6	2813-7304	6 /63
Gharko	13.9	30.3	3084-6801	5 /30
Kutiah	9.7	50.5	2869-7312	1 / 5
Sachen	8.5	9.5	3359-5026	7 /44
Chhungphar	7.3	24.9	2870-4734	3/16

3 sub-basin, 7 glacier,
28 profile, point **192**。

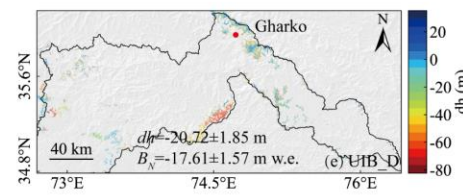
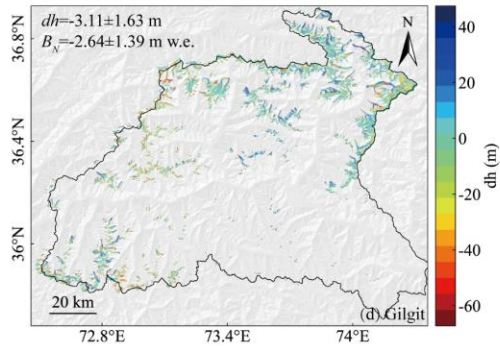
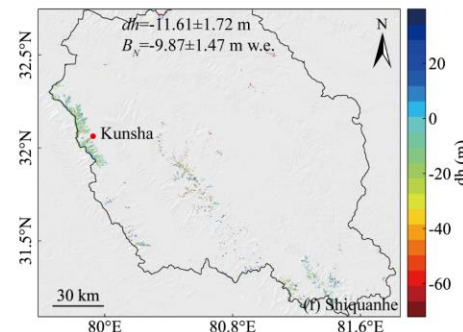
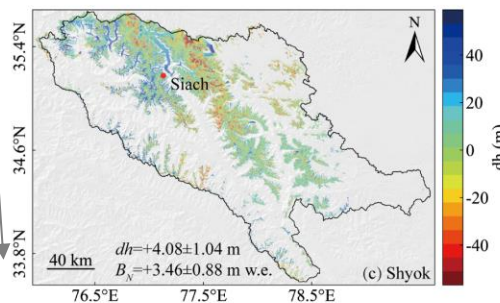
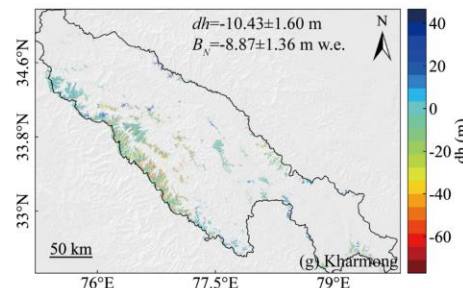
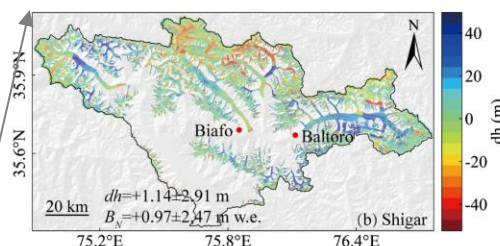
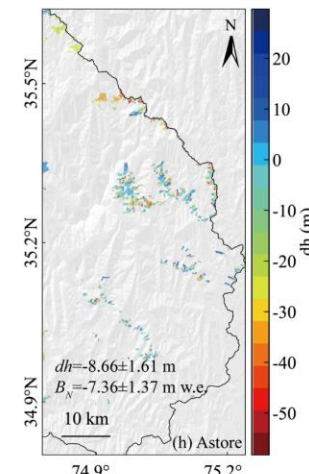
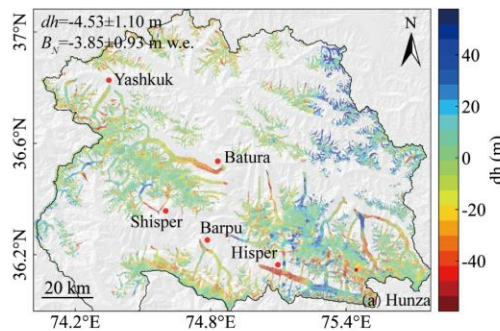
Changes of Glacier area



Region	Sub-basin	Changing rate (%)		
		Before 2000	After 2000	1980-2018
Karakoram	Hunza	-1.94%	-4.46%	-6.32%
	Shigar	-0.35%	-0.54%	-0.89%
	Shyok	-10.94%	-19.16%	-28.00%
Hindukush	Gilgit	-2.69%	-9.43%	-11.86%
	UIB_D	-0.16%	-4.00%	-4.15%
Western Himalaya	Astore	-1.68%	+2.98%	+1.23%
	Kharmong	-28.71%	-19.39%	-42.53%
	Shiquanhe	-14.78%	-52.31%	-59.36%
	UIB	-10.30%	-13.28%	-22.21%

Changes of Glacier surface elevation

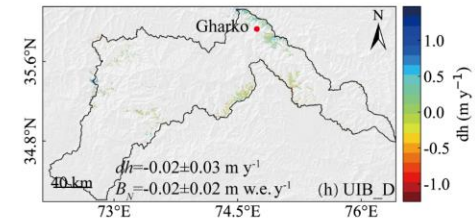
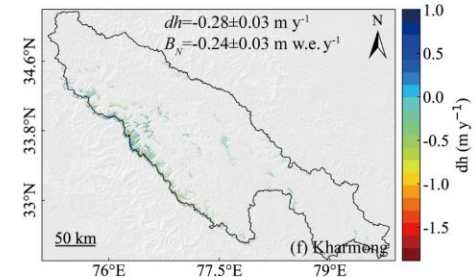
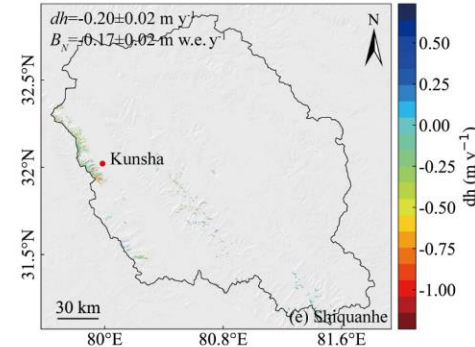
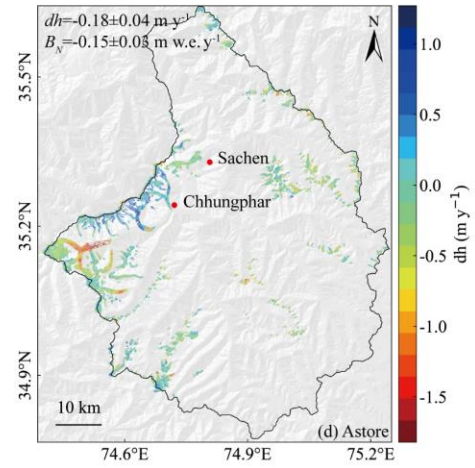
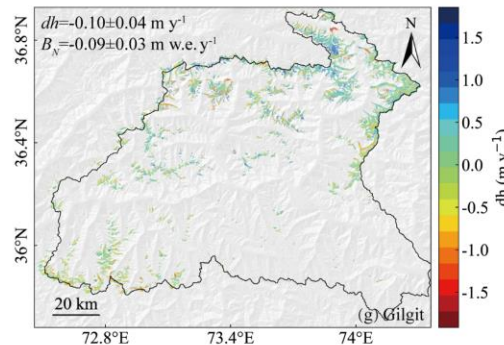
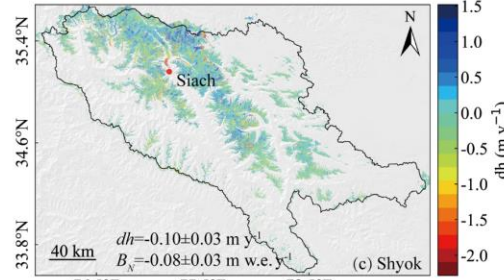
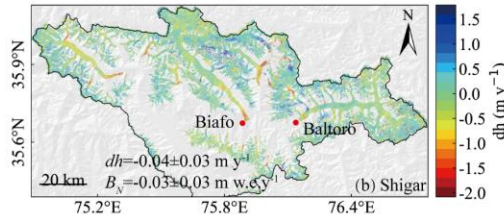
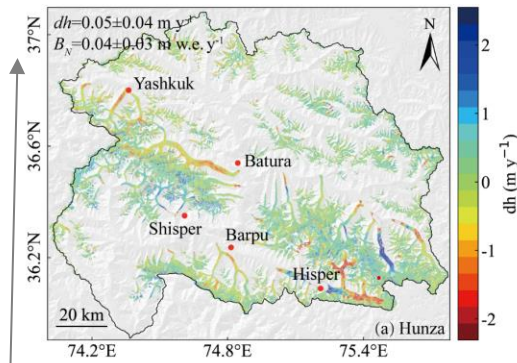
➤ 1973-2000



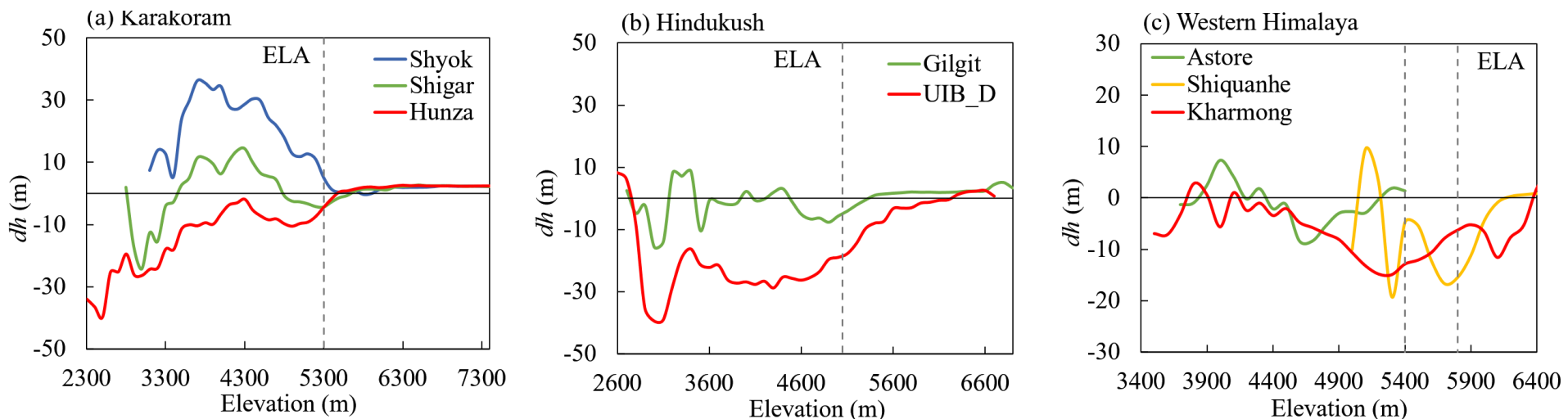
Region	Sub-basin	dh (m)	B_N (m w.e.)	ΔV (km^3)
Karakoram	Hunza	-4.53 ± 1.10	-3.85 ± 0.93	-20.78 ± 1.10
	Shigar	$+1.14 \pm 2.91$	$+0.97 \pm 2.47$	$+3.63 \pm 2.91$
	Shyok	$+4.08 \pm 1.04$	$+3.46 \pm 0.88$	$+43.31 \pm 1.04$
Hindukush	Gilgit	-3.11 ± 1.63	-2.64 ± 1.39	-4.46 ± 1.63
	UIB_D	-20.72 ± 1.85	-17.61 ± 1.57	-26.04 ± 1.85
Western Himalaya	Astore	-8.66 ± 1.61	-7.36 ± 1.37	-3.02 ± 1.61
	Kharmong	-10.43 ± 1.60	-8.87 ± 1.36	-2.81 ± 1.60
	Shiquanhe	-11.61 ± 1.72	-9.87 ± 1.47	-6.33 ± 1.72

Changes of Glacier surface elevation

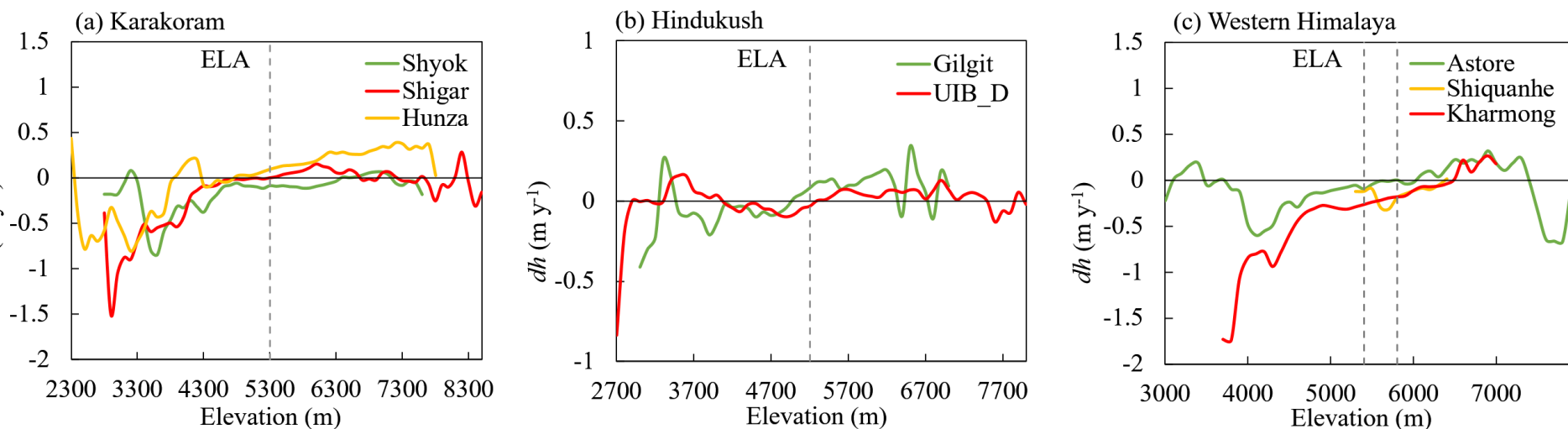
Region	Sub-basin	dh (m yr ⁻¹)	B_N (m w.e. yr ⁻¹)	ΔV (km ³ yr ⁻¹)
Karakoram	Hunza	+0.06±0.05	+0.05±0.04	+0.26±0.05
	Shigar	-0.03±0.05	-0.03±0.04	-0.11±0.05
	Shyok	-0.10±0.05	-0.08±0.04	-0.93±0.05
Hindukush	Gilgit	-0.02±0.06	-0.01±0.05	-0.02±0.06
	UIB_D	-0.02±0.04	-0.02±0.03	-0.03±0.04
Western Himalaya	Astore	-0.18±0.05	-0.15±0.04	-0.06±0.05
	Kharmong	-0.28±0.05	-0.23±0.04	-0.78±0.05
	Shiquanhe	-0.16±0.04	-0.14±0.03	-0.06±0.04



Altitude distribution of Changes of Glacier surface elevation 1973-2000



Altitude distribution of Changes of Glacier surface elevation 2000-2018



Glacier ice volumes changes during 1973-2018/2015

Region	Sub-basin	1973-2000				2000-2015/2018				1973-2015/2018			
		ΔA (km ²)	%	dh (m)	ΔV (km ³)	ΔA (km ²)	%	dh (m)	ΔV (km ³)	ΔA (km ²)	%	dh (m)	ΔV (km ³)
Karakoram	Hunza	-64	-1.9	-4.5	-20.8	-143	-4.5	+1.1	+4.7	-207	-6.3	-3.5	-16.1
	Shigar	-9	-0.4	+1.1	+3.6	-14	-0.5	-0.6	-2.0	-23	-0.9	+0.5	+1.7
	Shyok	-1074	-10.9	+4.1	+43.3	-1675	-19.2	-1.8	-16.7	-2749	-28.0	+2.3	+26.7
Hindukush	Gilgit	-31	-2.7	-3.1	-4.5	-106	-9.5	-1.8	-0.4	-137	-11.9	-4.9	-4.9
	UIB_D	-1	-0.2	-20.7	-26.0	-39	-4.0	-0.4	-0.5	-40	-4.2	-21.3	-26.6
Western Himalaya	Astore	-5	-1.7	-8.7	-3.0	+9	+3.0	-3.2	-1.1	-4	+1.2	-11.8	-4.1
	Kharmong	-1038	-28.7	-10.4	-2.8	-500	-19.4	-5.0	-14.0	-1538	-42.5	-6.4	-16.8
	Shiquanhe	-56	-14.8	-11.6	-6.3	-167	-52.3	-2.9	-1.0	-223	-59.4	-14.5	-7.2

- "Karakoram anomaly" occurred in Hunza after 2000, but in Shigar and Shyok before 2000;
- Comparing to area change, surface change is more important to glacier changes



Thanks for watching and suggestion