

The Cryosphere

Supplementary Materials for

Brief communication: Tropical glaciers on Puncak Jaya (Irian Jaya/West Papua, Indonesia) close to extinction

David Ibel*, Thomas Mölg, Christian Sommer

*corresponding author (E-Mail: david.ibel@fau.de)

Content:

Tables S1 – S5

Supplementary Table S1: Glacier surface area extents from ~1850 to 2024. This table is based on previous work conducted by Klein and Kincaid 2006 (10.3189/172756506781828818) and was enhanced by data of additional works (cited within the table) and our own surveys.

Glaciated area	~1850 ¹	1913 ¹	1936 ¹	1942 ¹	1962 ¹	1972 ¹	1974 ²	1987 ³	2000 ⁴	2002 ⁴	2005 ⁵	2012 ⁶	2015 ^{7,8}	2016 ⁸	2018 ⁸	2023 ⁹	2024 ¹⁰
Total size of glacier areas (Puncak Jaya)	19.3		13	9.9		7.3	6.4	3.0 [5.09]	2.33	2.15	1.72	0.931	0.58±0.016 (0.653±0.029)	0.546±0.026 [0.545]	0.458±0.036 [0.467]	0.196	0.165
Northwall Firm/Meren-glacier system	14.2		11.1	8.1		5.8	4.9	[3.6]	1.58	1.45	1.17	0.695	0.43	[0.406]	[0.348]	0.146	0.121
West and East Northwall Firm	9.1		8.3	5.5		3.6	2.8										
W. Northwall Firm			6.7	4.4		[1.3]			0.35	0.28	0.18		-		-	-	-
E. Northwall Firm			1.6	1.1									0.43			0.146	0.121
Meren glacier	5.1		2.8	2.6	2.1	2.2	2.1		-	-	-		-		-	-	
E. Northwall Firm and Meren glacier ¹¹			4.4	3.7				[2.3]	1.23	1.17	0.98						
Carstensz glacier system	3.6		1.6	1.5		1.4	1.4	[1.4]	0.75	0.7	0.55	0.236	0.15	[0.139]	[0.119]	0.051	0.044
Carstensz glacier	2.5		1.25	1.1	0.95				0.75	0.7	0.55		0.15	0.139	0.119	0.051	0.044
Wollaston glacier ¹²	0.5	0.3	0.2			0.17		-	-	-	-		-		-	-	-
Van de Water glacier ¹²	0.6	0.2	0.15			0.14		-	-	-	-		-		-	-	-
Southwall Hanging Glaciers	1.0	0.4	0.3	0.3		0.1	0.1	[0.09]			<0.1		-		-	-	-
Harrer glacier	0.5		<0.1	<0.1	<0.1	<0.05		-	-	-	-		-		-	-	-

¹ Allison and Peterson 1976: 28-34; ² Allison and Peterson 1989: H18; ³ Peterson and Peterson 1994: 3 [Figures in square brackets after GIS correction of the glacier area of Peterson and Peterson (1994) by Klein and Kincaid 2006: 72]; ⁴ Klein and Kincaid 2006: 72; ⁵ according to Table 4 and 5 in Kincaid 2007: 62-63; ⁶ own survey using PlanetScope data; ⁷ according to Table 3 in Veettil and Wang 2018: 499 (Figures in rounded brackets according to Figure 3 in Permana et al. 2019: 26384); ⁸ according to Figure 3 in Permana et al. 2019: 26384 [data in square brackets according to a result of own survey using PlanetScope data]; ⁹ own survey using PlanetScope data; ¹⁰ own survey using PlanetScope data; ¹¹ Due to its small size, the Meren Glacier could no longer be differentiated from the East Northwall Firm as an independent glacier from 1974 onwards. Therefore, both glaciers were considered as one unit after 1974 (Klein and Kincaid 2006: 72); ¹² As of 1972, Wollaston and Van de Water Glacier could no longer be reliably distinguished from each other or from Carstensz Glacier due to their small size (Klein and Kincaid 2006: 72);

Supplementary Table S2: PlanetScope and Pléiades scenes used to survey glacier extent in 2023 and 2024. Pléiades imagery was used to compensate for uncertainties in PlanetScope imagery due to its very high spatial resolution.

Provider/Mission	PlanetLabs/PlanetScope	PlanetLabs/PlanetScope	Airbus DS/Pléiades
Recording date/time	08.10.2023	29.06.2024 / 00:32 pm	08.10.2023 / 01:17:48 pm
Product type	PlanetScope Ortho Scene (PSB.SD)	PlanetScope Ortho Scene (PSB.SD)	Pléiades Ortho
Image processing level	,Visual‘	,Visual‘	,‘ / ,Display‘
Product ID	20231008_002131_43_24c7 (Collection: 1306a2cb-84e6-496f-a7dc-8d8ed3fc001e)	20240629_003211_68_24c9	DS_PHR1B_202310080117111 _FR1_PX_E137S05_0323_00435
Horizontal resolution	3 m	3 m	0.5 m
Solar elevation	56°	45.8°	69.51°
Viewing angle	3.8°	0.7°	5.3°

Supplementary Table S3: Sentinel 2 scene used to control the orthorectification of the PlanetScope and Pléiades scenes used (Table S2)

	Sentinel 2
Recording date/time	09.03.2023/ 01:17 pm
Product type	INS-NOBS, L2A
Image processing level	,Visual‘
Product ID	S2A_MSIL2A_20230309T011721_ N0509_R088_T53MQR_ 20230309T033024.SAFE (T53MQR_20230309T011721_TCI_10m)
Horizontal resolution	10 m

Supplementary Table S4: Additional RapidEye and PlanetScope scenes used to conduct additional surveying of glacier surface area extent in 2012, 2016 and 2018. Data derived from these surveys were used in Figure 1 (Top Right)

Provider/Mission	PlanetLabs/RapidEye	PlanetLabs/PlanetScope	PlanetLabs/PlanetScope
Recording date/time	26.02.2012 / 02:13 pm	16.05.2016 / 00:48 pm	28.03.2018 / 00:37 pm
Product type	RapidEye OrthoTile	PlanetScope Ortho Scene (PS2)	PlanetScope Ortho Scene (PS2)
Image processing level	,Visual‘	,Visual‘	,Visual‘
Product ID	20120226_021311_5337225_RapidEye-4	20160516_004847_0c18	20180328_003744_0f51
Horizontal resolution	5 m	3 m	3 m
Solar elevation	76.44°	52.7°	54.6°
Viewing angle	0.12°	1.3°	0.1°

Supplementary Table S5: Overview of quantitative changes of Puncak Jaya glaciers. Note that East Northwall Firn Mid and East were one entity in 2018. “Label” refers to labelled glacier areas shown in Figure 2.

Label	Glacier	Area in m ²		
		2018	2023	2024
1,2,3	East Northwall Firn	359.932	145.798	120.812
1	East Northwall Firn (West)	98.589	26.222	21.707
2	East Northwall Firn (Mid)	261.343	76.164	63.759
3	East Northwall Firn (East)		43.412	35.346
4	Carstensch	117.806	50.694	44.443
Total	Puncak Jaya	477.738	196.492	165.255
		0.478 km ²	0.196 km ²	0.165 km ²