Supplement of The Cryosphere, 8, 1297–1315, 2014
http://www.the-cryosphere.net/8/1297/2014/
doi:10.5194/tc-8-1297-2014-supplement
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The Cryosphere
Open Access

Supplement of

Tracing glacier changes since the 1960s on the south slope of Mt. Everest (central Southern Himalaya) using optical satellite imagery

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Table S1. A complete set of data on glacier surface area (Surf), terminus (Term), snow-line altitude (SLA) and debris cover area (DebrisCov) for all analysed glaciers.

Glacier	Surface area (km^2)						Terminus difference (m)						SLA (m a.s.l.)						Debris-cover area (%)					
	1962	1975	1992	2000	2008	2011	1962-75	1975-92	1992-00	2000-08	2008-11	1962-11	1962	1975	1992	2000	2008	2011	1962	1975	1992	2000	2008	2011
Ama Dablam	10.6	10.5	10.4	10.3	9.8	9.6	39	-44	-56	-86	-39	-186	5183	5199	5247	5264	5337	5387	23	23	25	24	25	26
Bhote Koshi	43.7	43.6	43.2	43.1	42.9	42.7	-140	-215	-80	-146	-42	-623	5224	5382	5492	5544	5606	5632	27	30	37	40	41	41
Chhule	10.2	9.8	9.1	8.8	8.0	7.7	-65	-40	-152	-169	-7	-433	5139	5231	5288	5342	5368	5364	18	24	20	21	26	28
Chhutingpo	8.5	9.3	7.6	7.2	6.5	7.0	-78	-136	-168	-45	0	-427	5324	5257	5321	5299	5360	5372	-	-	5	4	5	5
Cholo	2.3	2.9	1.9	1.5	1.4	1.4	234	212	-74	-15	0	357	4987	4946	5062	5098	5124	5152	40	35	45	59	62	63
Cholotse	2.5	1.7	1.5	1.5	1.5	1.5	0	96	0	-98	-28	-30	5078	5141	5183	5195	5262	5244	44	63	66	76	82	75
Duwo	2.2	2.2	2.1	2.2	2.1	2.1	182	172	-99	0	0	255	-	4984	4969	4985	5039	-		33	39	40	48	-
Imja	28.1	28.0	27.0	27.2	26.4	25.5	-862	-458	-336	-255	-207	-2119	5340	5480	5655	5673	5691	5742	25	23	23	23	25	27
Kdu_gr125	1.9	1.7	1.5	1.4	1.0	0.9	-182	-153	-88	-123	-56	-601	5444	5462	5448	5423	5444	5442	17	-	0	-	-	12
Kdu_gr181	1.3	1.1	1.4	0.7	0.6	0.6	0	0	0	0	0	0	5219	-	-	-	5350	-	-	-	-	-	4	-
Kdu_gr38	2.8	2.1	1.6	0.9	0.8	0.7	-142	-420	-192	-345	-45	-1143	5208	5305	5246	5298	5368	5490	-	-	2	-	-	18
Khangri	18.6	19.1	18.6	17.9	18.5	17.2	0	0	0	0	0	0	5352	5383	5432	5451	5533	5584	25	27	30	32	33	37
Khumbu	40.1	38.9	38.0	38.4	38.4	37.5	0	54	-14	0	0	41	5403	5545	5519	5508	5681	5730	15	19	19	20	23	24
Kyajo	1.6	1.7	1.2	1.0	1.0	1.0	65	-110	0	0	-9	-54	5433	-	5385	5325	5388	5366	-	-	-	-	9	35
Langdak	3.0	2.6	2.0	2.3	2.1	2.2	-117	-426	-103	-115	-103	-863	5193	5094	5249	5206	5214	5220	39	27	38	35	40	41
Langmuche	5.5	4.9	3.7	3.3	2.9	2.8	-598	-350	-27	-203	-112	-1290	5184	5150	5168	5147	5202	5191	12	16	3	6	8	10
Lhotse	15.6	16.8	15.9	15.3	15.4	14.6	0	231	-63	-188	-42	-62	5463	5429	5425	5544	5664	5713	36	31	40	42	45	42
Lobuje	2.0	1.7	1.7	1.8	1.7	1.7	0	-20	-37	0	0	-57	5347	5350	5418	5522	5578	5628	34	35	39	41	43	46
Lumsamba	20.4	21.6	22.9	20.8	19.3	18.4	0	0	0	0	0	0	5445	5518	5454	5480	5582	5608	23	24	19	22	29	31
Machhermo	2.1	2.5	1.9	1.1	1.2	1.2	-166	-302	25	105	0	-339	5361	-	5443	5330	5303	5552	9	-	-	-	-	26
Melung	12.0	11.6	11.4	11.3	10.9	10.8	-234	-425	-45	-170	-46	-919	5263	5339	5386	5440	5493	5480	29	29	32	32	34	30
Nare	9.3	7.6	6.9	6.6	6.0	5.8	-359	-48	-329	-165	-66	-966	5332	5308	5295	5266	5356	5436	15	20	25	24	25	27
Nareyargaip	6.9	6.1	6.4	5.9	5.5	5.5	-186	-74	-40	0	0	-301	5361	5452	5442	5460	5509	5528	27	37	35	41	47	40
Ngojumba	98.7	98.7	98.3	98.0	97.7	97.3	-82	-176	-48	-125	-24	-455	5381	5532	5496	5507	5568	5570	27	27	26	27	28	30
Nuptse	9.2	9.2	8.8	8.0	8.1	7.9	-79	92	0	0	0	14	5515	5505	5615	5569	5574	5588	28	31	35	36	38	37
Phunki	2.0	1.7	1.7	1.8	1.7	1.6	-156	-296	-189	-174	0	-815	-	-	-	-	5028	-	-	-	-	-	-	-
Thyangbo	15.3	14.7	13.6	12.1	8.8	8.6	-210	-36	-72	0	-143	-460	5079	5049	5139	5247	5271	5289	12	10	9	12	20	26
Tingbo	1.5	1.4	1.3	1.2	1.1	1.2	-169	68	-64	0	0	-165	5402	5262	5271	5328	5370	5431		21	40	38	39	40
W-Lhotse	5.6	5.0	4.7	5.0	4.5	4.4	-52	114	16	-46	-70	-39	5299	5252	5280	5384	5398	5492	31	33	37	36	39	40
Other glaciers (< 1 km^2)	21.0	19.4	19.0	16.7	12.4	12.1	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-

Table S2. Morphological parameters (slope, aspect, elevation and length) of the glaciers for 1962-2011.

Glacier	Slope (deg)						Aspect (deg)						Elevation (m)																		Length of ablation area (km)
													1962			1975			1992			2000			2008			2011			
	1962	1975	1992	2000	2008	2011	1962	1975	1992	2000	2008	2011	Avg.	Min	Max.	Avg.	Min	Max.	Avg.	Min	Max.	Avg.	Min	Max.	Avg.	Min	Max.	Avg.	Min	Max.	
Ama Dablam	29.6	28.1	26.9	29.8	28.7	29.5	236	227	234	236	244	239	5422	4768	6640	5355	4715	6665	5374	4758	6417	5412	4736	6672	5412	4775	6359	5425	4787	6359	4.32
Bhote Koshi	24.3	25.9	24.8	23.6	25.0	24.2	174	170	174	136	168	172	5552	4725	6979	5574	4739	7097	5578	4739	7080	5525	4758	6893	5555	4772	6893	5559	4766	6899	10.46
Chhule	25.3	26.6	24.8	23.5	24.0	21.2	133	120	119	113	111	112	5318	4818	6545	5151	4818	6286	5112	4766	6264	5119	4766	6268	5080	4787	5836	5240	4809	6220	6.02
Chhutingpo	27.3	27.6	26.7	26.0	28.0	26.4	149	133	140	126	155	144	5519	4915	6182	5539	4856	6288	5554	4905	6206	5552	4947	6182	5636	5081	6182	5598	5008	6188	0.95
Cholo	35.7	35.5	31.8	33.1	30.0	30.7	105	105	104	101	103	103	5258	4519	6442	5239	4420	6423	5193	4358	6442	5006	4422	6248	4907	4422	6146	4940	4407	6215	2.21
Cholotse	33.5	27.5	24.2	23.6	24.4	24.6	248	244	226	225	209	235	5338	4865	6281	5319	4883	6301	5270	4846	6301	5111	4857	5588	5098	4851	5660	5108	4879	5662	1.65
Duwo	30.3	32.9	31.9	34.2	30.0	30.1	210	237	227	215	217	218	5198	4746	6654	5169	4719	6452	5191	4719	6452	5236	4749	6332	5101	4744	5973	5103	4740	5973	1.70
Imja	30.2	33.1	32.1	33.5	32.8	33.1	210	204	210	168	215	218	5768	4980	7971	5807	4981	8226	5833	4986	8226	5844	4989	7803	5877	4981	7803	5877	5007	7803	6.89
Kdu_gr125	26.1	27.9	25.7	24.9	18.2	17.6	168	170	172	170	164	162	5540	5118	6005	5592	5255	6097	5605	5258	6097	5601	5329	6102	5522	5332	5759	5515	5361	5695	0.85
Kdu_gr181	46.9	41.7	41.0	41.4	41.8	43.1	215	231	239	231	243	233	5526	4834	6547	5677	4844	6572	5541	4724	6572	5544	4936	6572	5480	4899	6527	5548	4991	6527	-
Kdu_gr38	38.4	40.7	38.0	39.8	38.8	39.7	87	85	77	75	90	74	5463	4800	6603	5487	4878	6527	5478	4939	6527	5594	4917	6504	5708	4917	6529	5626	4947	6511	0.57
Khangri	25.2	25.4	24.7	23.3	23.2	23.3	168	160	167	153	160	160	5597	5081	7105	5581	5027	7111	5605	5027	7111	5558	5100	6844	5568	5100	6844	5557	5091	6844	3.73
Khumbu	29.7	30.6	30.4	30.2	29.7	29.5	212	211	212	192	205	207	6058	4844	8289	6116	4876	8159	6163	4876	8260	6175	4900	8250	6152	4909	8250	6150	4880	8260	8.99
Kyajo	19.4	20.7	15.9	15.8	16.0	13.9	120	123	113	113	115	117	5419	5224	5939	5428	5224	5922	5385	5224	5575	5387	5224	5583	5393	5224	5595	5369	5224	5540	-
Langdak	23.7	25.6	21.4	24.3	22.3	25.9	143	148	130	141	127	166	5287	4803	6164	5399	4795	6179	5285	4737	6179	5315	4824	6126	5307	4820	5880	5297	4842	6155	2.65
Langmuche	35.8	40.6	39.0	40.4	40.7	40.4	114	99	105	97	116	91	5484	4348	6819	5613	4355	6804	5546	4370	6659	5673	4369	6804	5774	4418	6819	5681	4361	6804	2.61
Lhotse	31.3	33.3	31.7	29.6	29.8	30.7	206	203	207	203	202	207	5818	4800	8400	5907	4758	8467	5890	4758	8467	5818	4794	8472	5829	4816	8238	5907	4816	8472	5.53
Lobuje	23.7	22.3	21.9	22.8	21.8	21.2	134	137	145	130	139	140	5361	4960	5940	5379	4959	5997	5356	4923	5997	5382	4960	5885	5357	4960	5852	5352	4960	5843	1.98
Lumsamba	26.4	27.6	26.7	26.5	27.8	26.4	187	192	191	165	186	186	5784	4799	7274	5830	4908	7262	5796	4908	7262	5825	4931	7270	5866	4896	7274	5865	4931	7262	8.18
Machhermo	25.5	27.0	24.9	24.4	25.5	22.6	168	145	145	150	143	149	5505	5165	5991	5321	4819	5808	5447	5166	5808	5499	5208	5808	5499	5176	5814	5468	5166	5808	-
Melung	21.0	22.4	22.1	23.1	24.2	20.9	150	145	144	130	144	146	5349	4834	6600	5211	4950	5632	5164	4950	5578	5144	4950	5588	5157	4949	5530	5407	4950	6600	5.67
Nare	29.0	31.2	29.9	31.9	29.5	30.6	234	228	233	184	239	241	5382	4563	6388	5476	4721	6427	5482	4752	6476	5441	4803	6482	5392	4825	6305	5423	4827	6317	2.72
Nareyargaip	28.2	28.1	26.8	26.4	25.3	25.7	207	214	212	194	213	213	5596	5142	6672	5581	5129	6538	5535	5129	6665	5522	5105	6467	5503	5110	6294	5508	5110	6281	2.22
Ngojumba	23.8	24.5	24.0	24.1	24.5	23.9	185	179	184	133	182	181	5798	4680	8151	5814	4684	8115	5824	4674	8067	5848	4673	8109	5873	4684	8164	5844	4684	8115	15.79
Nuptse	30.8	30.9	31.0	28.9	29.2	29.2	214	212	218	147	211	210	5750	4932	7716	5804	4885	7754	5823	4885	7754	5744	4904	7716	5776	4932	7737	5769	4933	7716	5.15
Phunki	45.7	50.5	50.1	47.8	46.8	48.0	218	207	210	216	215	221	5367	4664	6548	5466	4720	6553	5465	4720	6553	5347	4811	6554	5304	4811	6548	5333	4823	6548	-
Thyangbo	37.0	37.6	36.7	37.2	33.1	33.0	139	131	129	131	130	123	5456	4324	6828	5417	4397	6638	5469	4335	6793	5490	4335	6783	5328	4385	6420	5323	4363	6480	2.91
Tingbo	33.3	36.3	34.8	30.4	29.3	30.9	250	241	241	235	241	237	5460	4899	6631	5576	4937	6677	5440	4886	6090	5342	4899	5955	5289	4899	5888	5347	4894	5955	1.33
W-Lhotse	32.6	35.0	35.7	33.2	34.4	33.4	210	201	203	196	204	197	5625	4942	7465	5727	4954	7649	5742	4954	7649	5633	4935	7072	5746	4924	7496	5654	4955	7072	2.94
Other glaciers (<1 km^2)	35.8	35.0	33.6	37.3	36.4	36.2	198	160	193	186	188	182	5397	4235	6441	5248	4359	6433	5365	4235	6442	5437	4498	6442	5397	4469	6442	5402	4533	6442	-

Table S3. Additional snow-line altitudes (SLAs) derived from 20 Landsat ETM+ imagery of 2000-2011 period for three selected glaciers: Lobuje, Khangri, and Imja. All these images, acquired in the October-December period, present no or minimum cloud cover.

Date	Scene ID	SLA position on glacier (m a.s.l.)		
		Lobuje	Khangri	Imja
10/14/2000	LE71400412000288SGS00	5521	5476	5669
10/17/2001	LE71400412001290SGS00	5514	5471	5644
10/20/2002	LE71400412002293SGS00	5494	5458	5657
11/8/2003	LE71400412003312ASN01	5575	5471	5657
10/25/2004	LE71400412004299PFS00	5555	5471	5663
11/10/2004	LE71400412004315PFS00	5568	5493	5682
10/28/2005	LE71400412005301PFS00	5548	5489	5672
11/13/2005	LE71400412005317EDC00	5591	5498	5685
11/16/2006	LE71400412006320PFS00	5581	5492	5695
12/2/2006	LE71400412006336SGS00	5571	5502	5660
10/18/2007	LE71400412007291PFS00	5564	5492	5673
11/19/2007	LE71400412007323PFS00	5579	5478	5695
10/20/2008	LE71400412008294PFS03	5524	5505	5660
12/7/2008	LE71400412008342SGS00	5576	5544	5664
10/23/2009	LE71400412009296SGS00	5545	5500	5695
11/8/2009	LE71400412009312SGS00	5549	5537	5720
10/26/2010	LE71400412010299SGS00	5558	5509	5697
11/11/2010	LE71400412010315PFS00	5549	5543	5672
10/29/2011	LE71400412011302EDC00	5593	5526	5742
12/16/2011	LE71400412011350PFS01	5612	5566	5733

Table S4. Reference studies on the surface area and terminus glacier changes in the Himalaya and Tibetan Plateau.

Geographic region[a]	Period	Rate	Area (km^2 approx.)[b]	Location	Source
(a) Surface area loss (% a^{-1})					
CH-S	1962-2011	0.27	400	Sagarmatha (Mt. Everest) National Park (SNP) Nepal	This study
CH-S	1976-2000	0.15	1100	Koshi basin Nepal	Yao et al. (2012)
CH-S	1950s-1992	0.14	400	SNP Nepal	Salerno et al. (2008)
CH-S	1962-2005	0.12	90	North-East of SNP Nepal	Bolch et al. (2008)
CH-N	1976-2006	0.50	2700	Mt.Qomolangma National Nature Preserve, TP	Nie et al. (2010)
CH-N	1974-2008	0.30	150	Mt. Qomolangma region, TP	Ye et al. (2009)
CH-N	1970-2001	0.29	650	Pumqu river basin, Tibetan Plataeu	Jin et al. (2005)
WH-S	1960-2004	0.40	6300	Western Himalaya	Kulkarni et al. (2011)
WH-S	1962-2004	0.50	2077	Chenab, Parbati and Baspa	Kulkarni et al. (2007)
WH-N	1969-2010	0.34	90	Kang Tatze Massif, Ladakh	Schmidt and Nusser (2012)
WH-N	1976-2003	0.30	80	Naimona'nyi region	Ye et al. (2006b)
EH-S	1990-2010	0.17	200	Sikkim Himalaya	Basnett et al. (2013)
EH-S	1997-2004	0.38	400	Tista basin	Kulkarni et al. (2011)
EH-S	1963-1993	0.30	130	Bhutan	Karma et al. (2003)
EH-N	1970-2009	0.32	150	Boshula, mountain, Southeastern TP	Wang et al. (2011)
TP	1970-2001	0.20	900	Nam Co Basin, Southeast of West Nyainqentanglha	Yao et al. (2012)
TP	1976-2009	0.30	800	Nam Co basin	Bolch et al. (2010)
(b) Terminus retreat (m a^{-1})					
CH-S	1962-2011	8.2	400 (29)	SNP Nepal	This study
CH-S	1970-1979	2.4	33 (11)	Khumbu region	Yamada et al. (1992)
CH-S	1974-1999	6.9	7 (3)	Nepal Himalaya	Yao et al. (2012)
CH-N	1960-2001	7.1	130 (3)	Mt. Qomolangma region, TP	Ren et al. (2006)
CH-N	1980-2001	6.4	30 (2)	Mt. Xixiabangma, TP	Ren et al. (2006)
WH-S	1962-2008	14.4	15 (2)	Garhwal Himalaya	Mehta et al. (2011)
WH	1960s-2000	16.6	-- (20)	Garhwal, Kumaun, Himachal and sourrounding	Yao et al. (2012)
EH-S	1963-1993	27.0	130 (66)	Bhutan Himalaya	Karma et al. (2003)
EH-S	1976-2005	13.0	-- (26)	Sikkim Himalaya	Raina (2009)
TP	1970-2007	16.3	55 (5)	Nyainqentanglha mountain region	Yao et al. (2012)

[a] CH, WH, EH, and TP represent Central Himalaya, Western Himalaya, Eastern Himalaya and Tibetan Plateau, respectively (suffixes -N and -S indicate the north and south, respectively);

[b] Numbers in bracket represent the number of glaciers

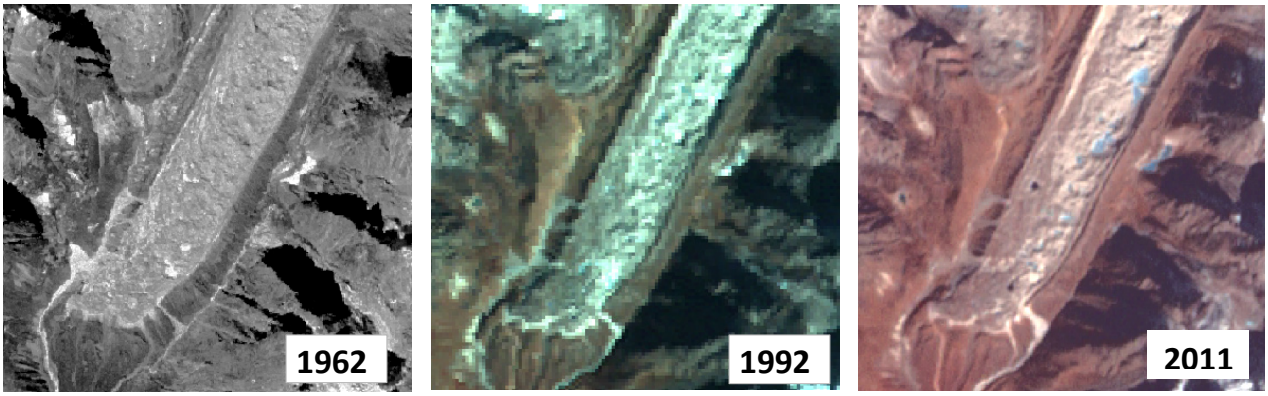

Fig. S1. The terminus of Khumbu glacier based on the 1962 Corona, 1992 Landsat TM, and 2011 Landsat ETM+ imagery. We can observe that since 1962 there is no retreat of the distal part of the terminus.

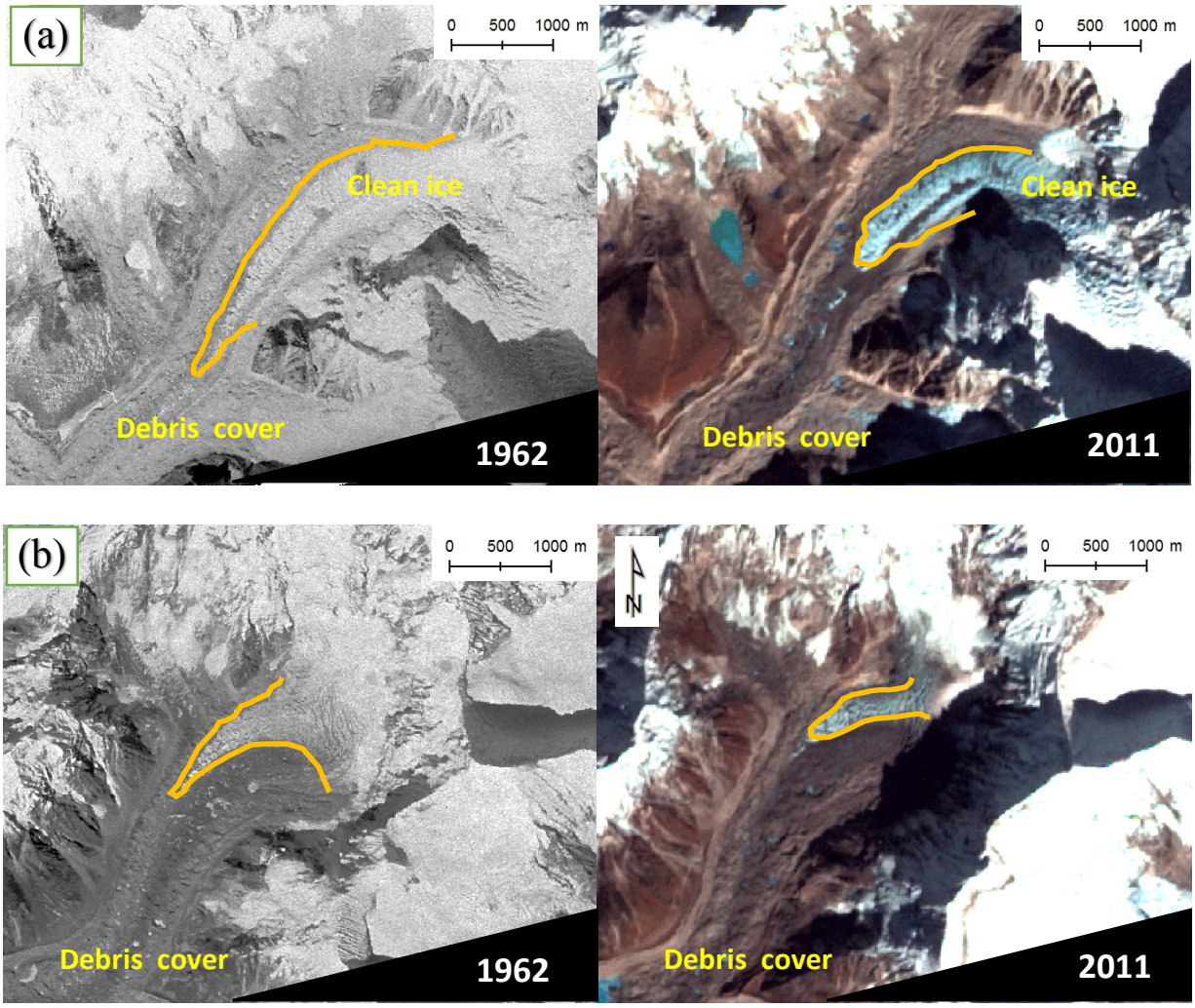

Fig. S2. Transition zone between debris cover and debris-free ice area of, **(a)** Khumbu glacier and **(b)** Imja glacier. The images clearly show an increase in the debris cover area between 1962 and 2011.

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