Supplemental Material

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Solar Radiation in the Arctic during the Early Twentieth-Century Warming (1921–50): Presenting a Compilation of Newly Available Data

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Content: Tables S1 and S2 contain detailed metadata of 42 measurement sites presented in Table 1 of the main paper. Figures S2–S9 are the same as Figures 2–9 of the main paper but are expressed in megajoules per meter squared.

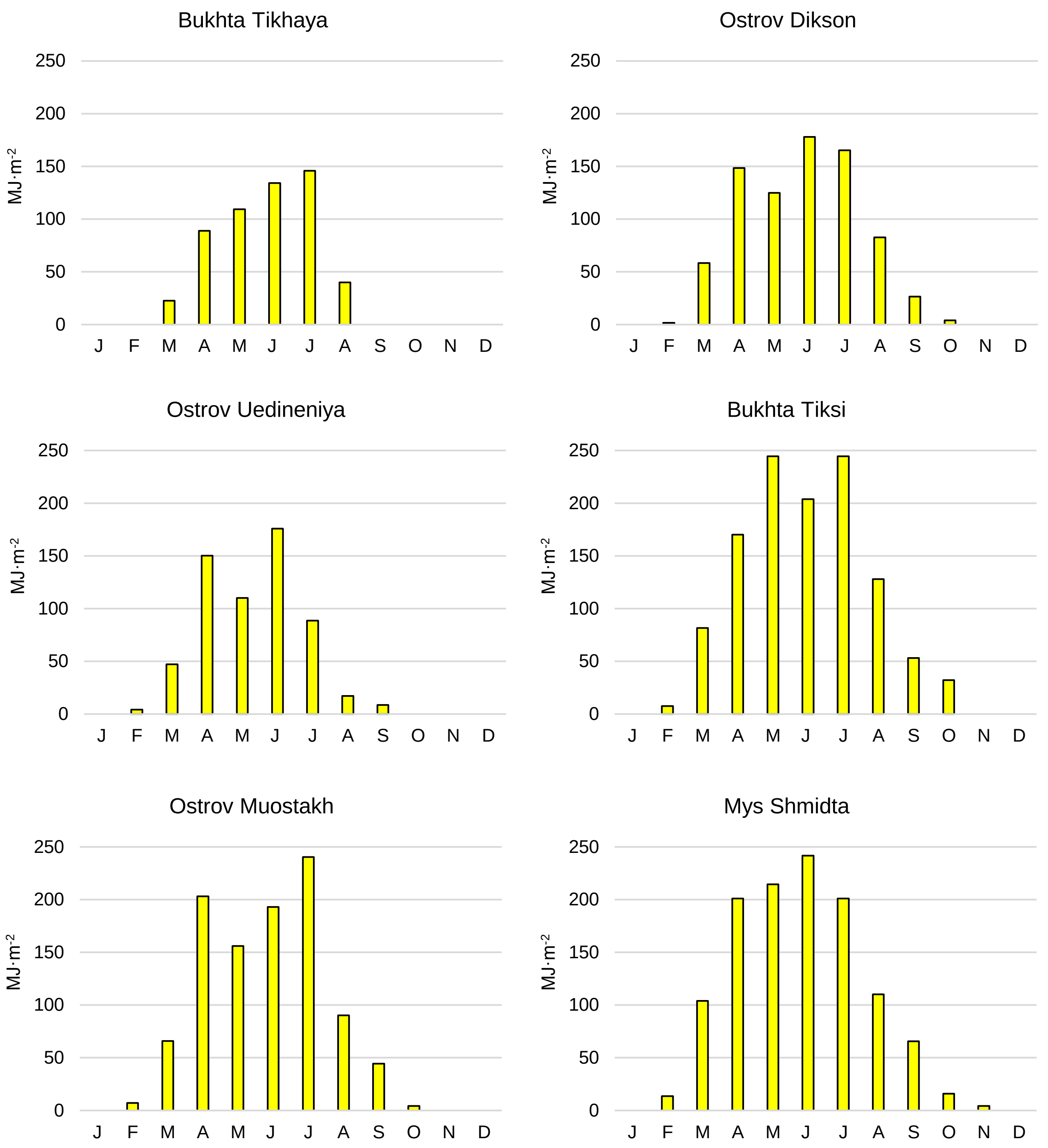


Fig. S2. Average monthly totals of direct solar radiation in the Russian Arctic during the ETCW

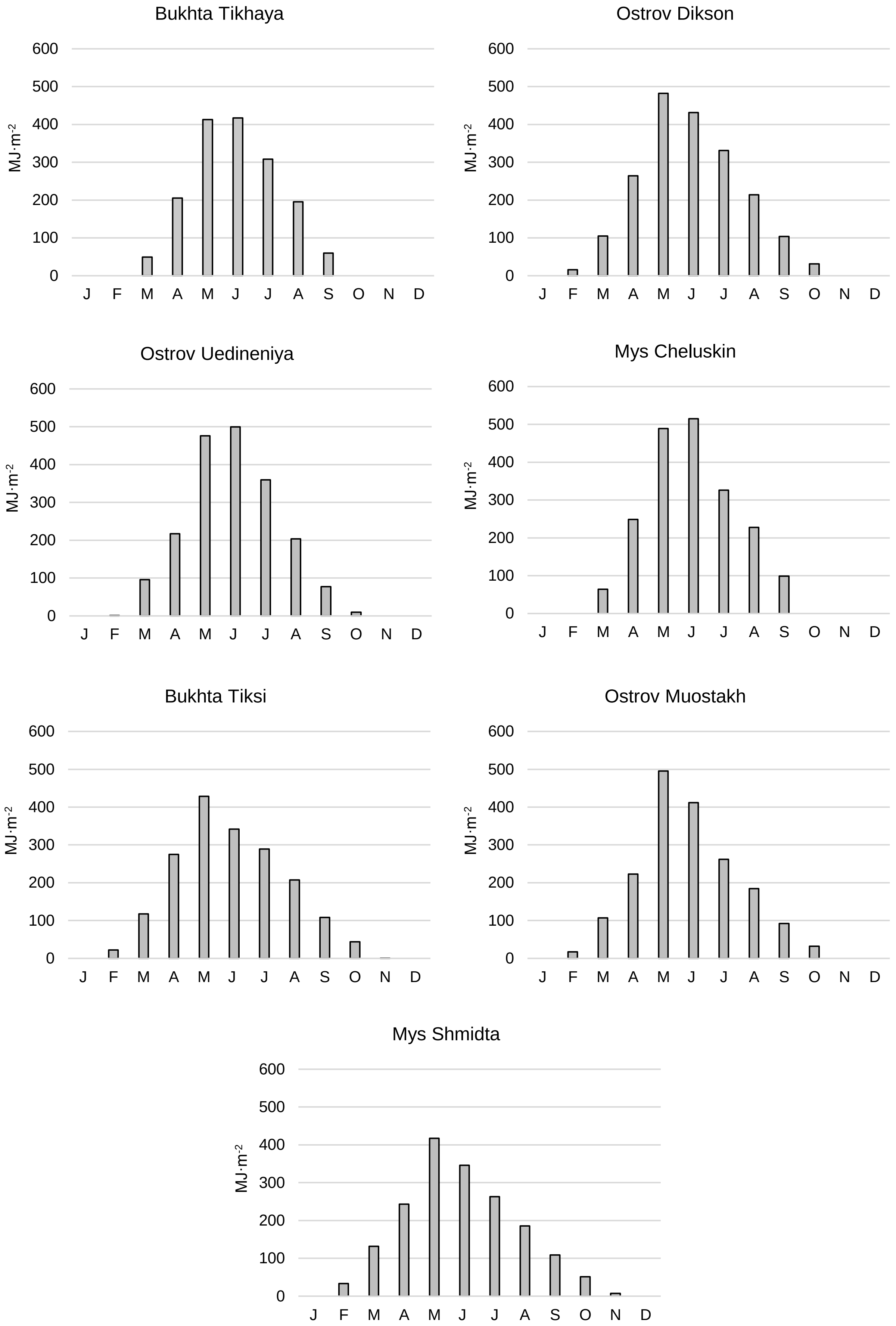


Fig. S3. Average monthly totals of diffuse solar radiation in the Russian Arctic during the ETCW

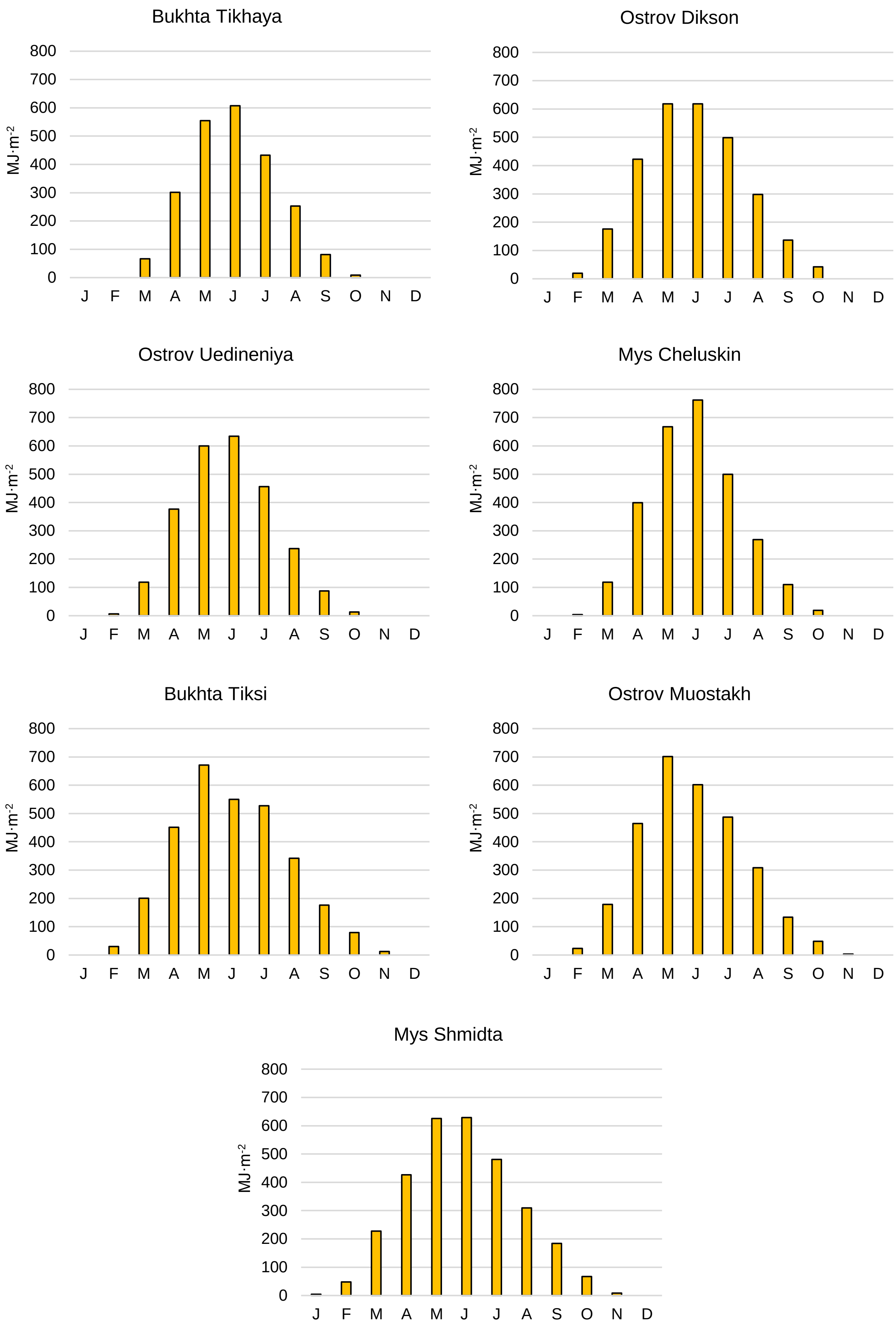


Fig. S4. Average monthly totals of global solar radiation in the Russian Arctic during the ETCW

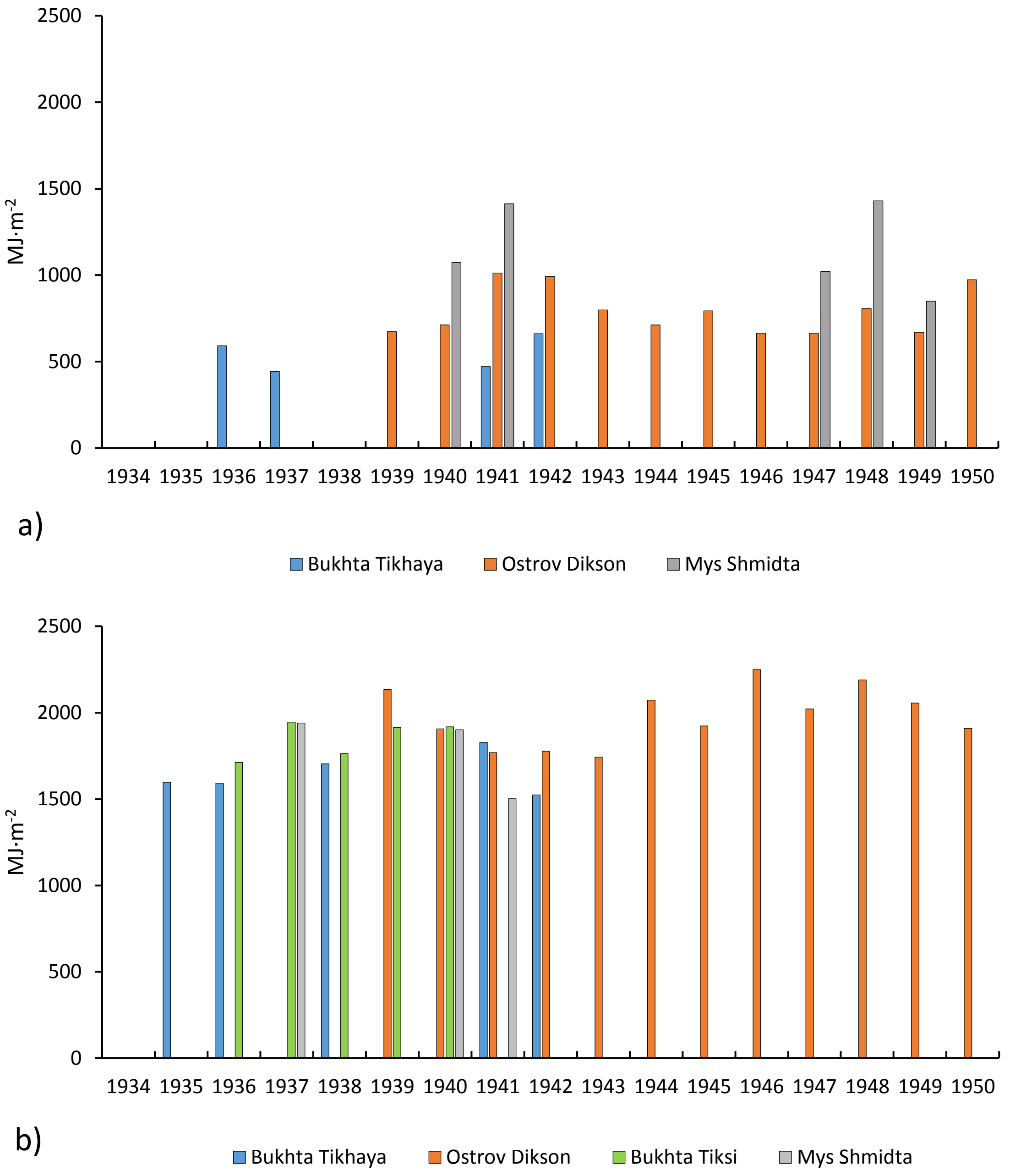
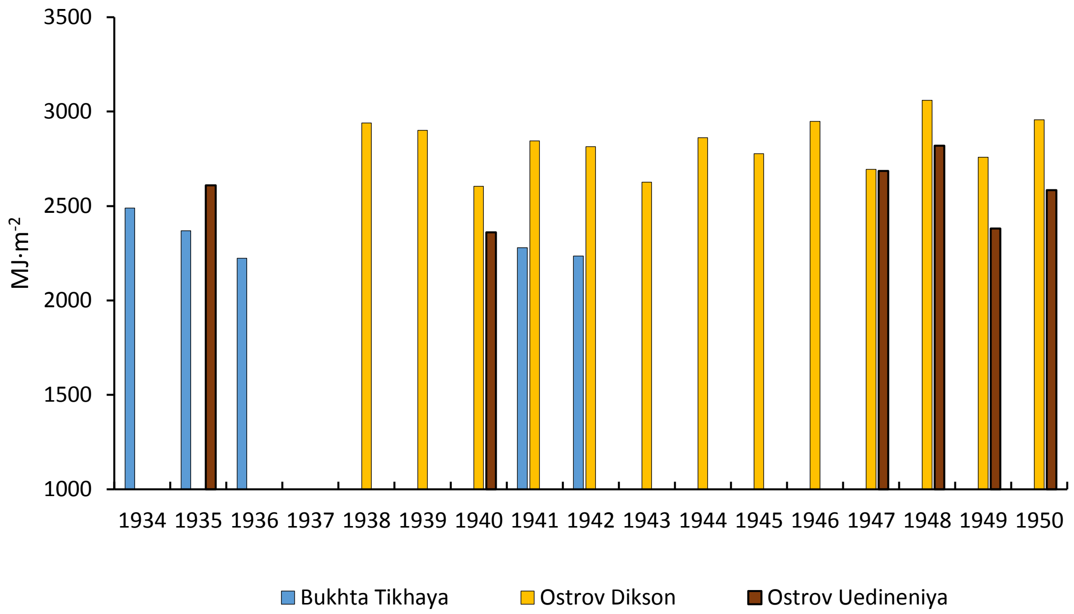


Fig. S5. Year-to-year courses of annual totals of direct (a) and diffuse (b) solar radiation in the Russian Arctic during the ETCW



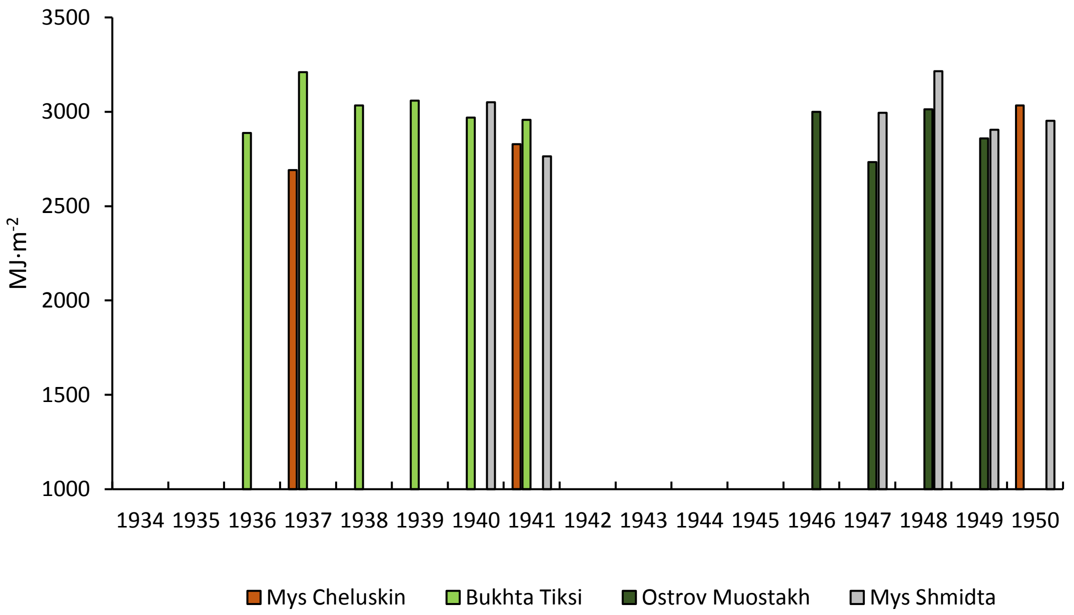


Fig. S6. Year-to-year courses of annual totals of global solar radiation in the Russian Arctic during the ETCW

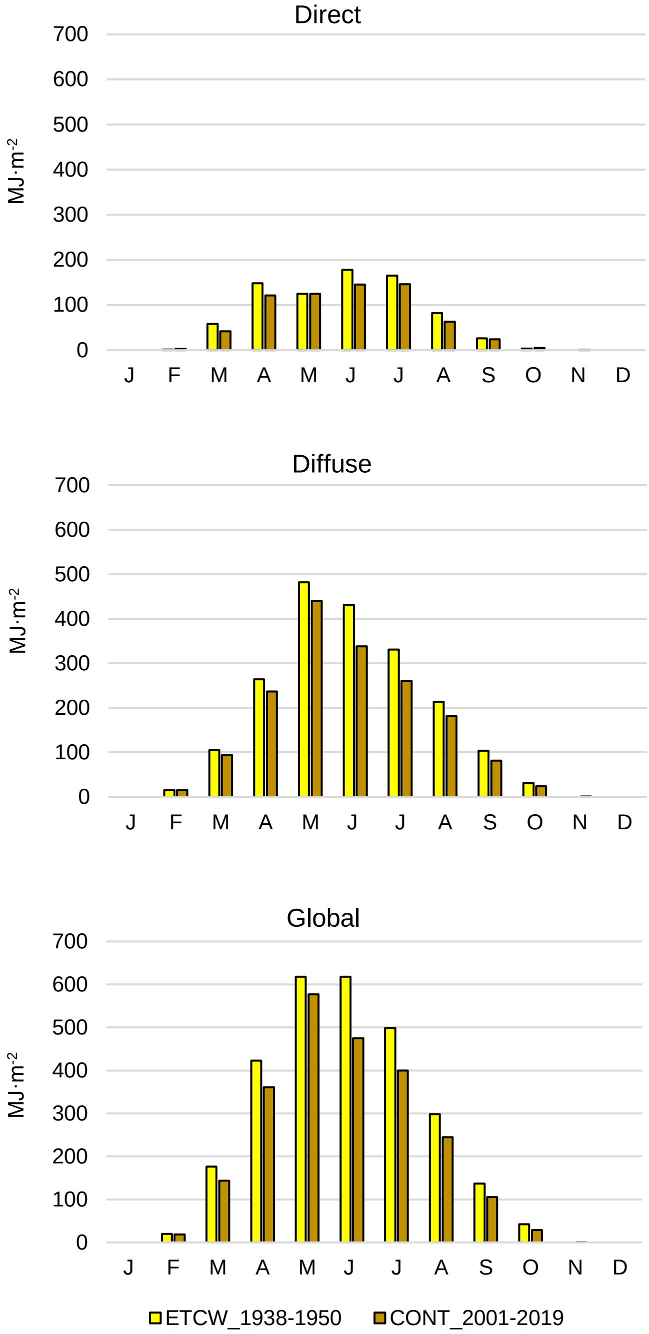


Fig. S7. Average monthly totals of direct, diffuse and global solar radiation during the ETCW (1938-50) and contemporary (CONT_2001-2019) periods in Ostrov Dikson (Russian Arctic)

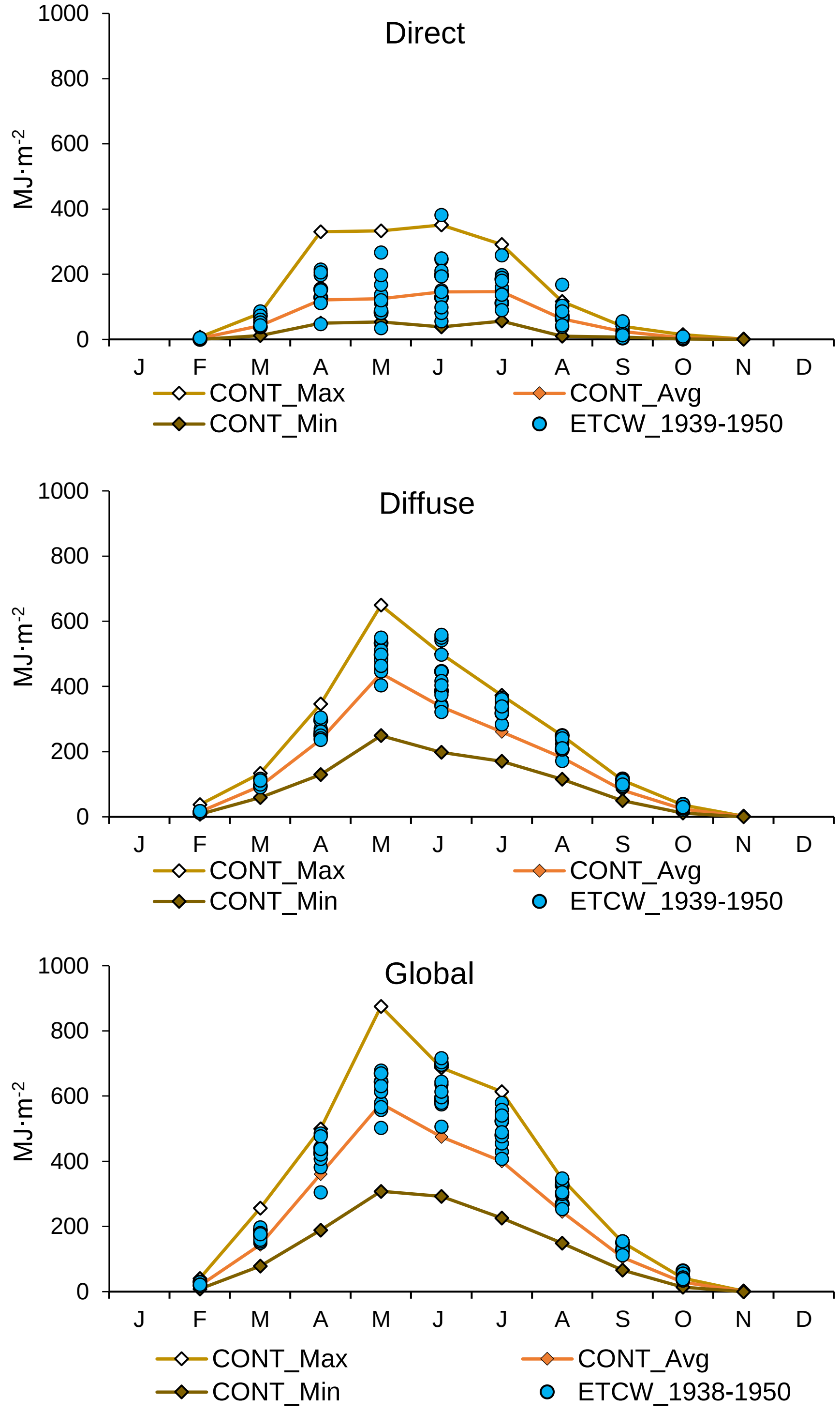


Fig. S8. Highest (CONT_Max), average (CONT_Avg) and lowest (CONT_Min) monthly totals of direct, diffuse, and global solar radiation in contemporary period (2001-19) and individual monthly totals available for the ETCW (ETCW_1938-1950) in Ostrov Dikson (Russian Arctic)

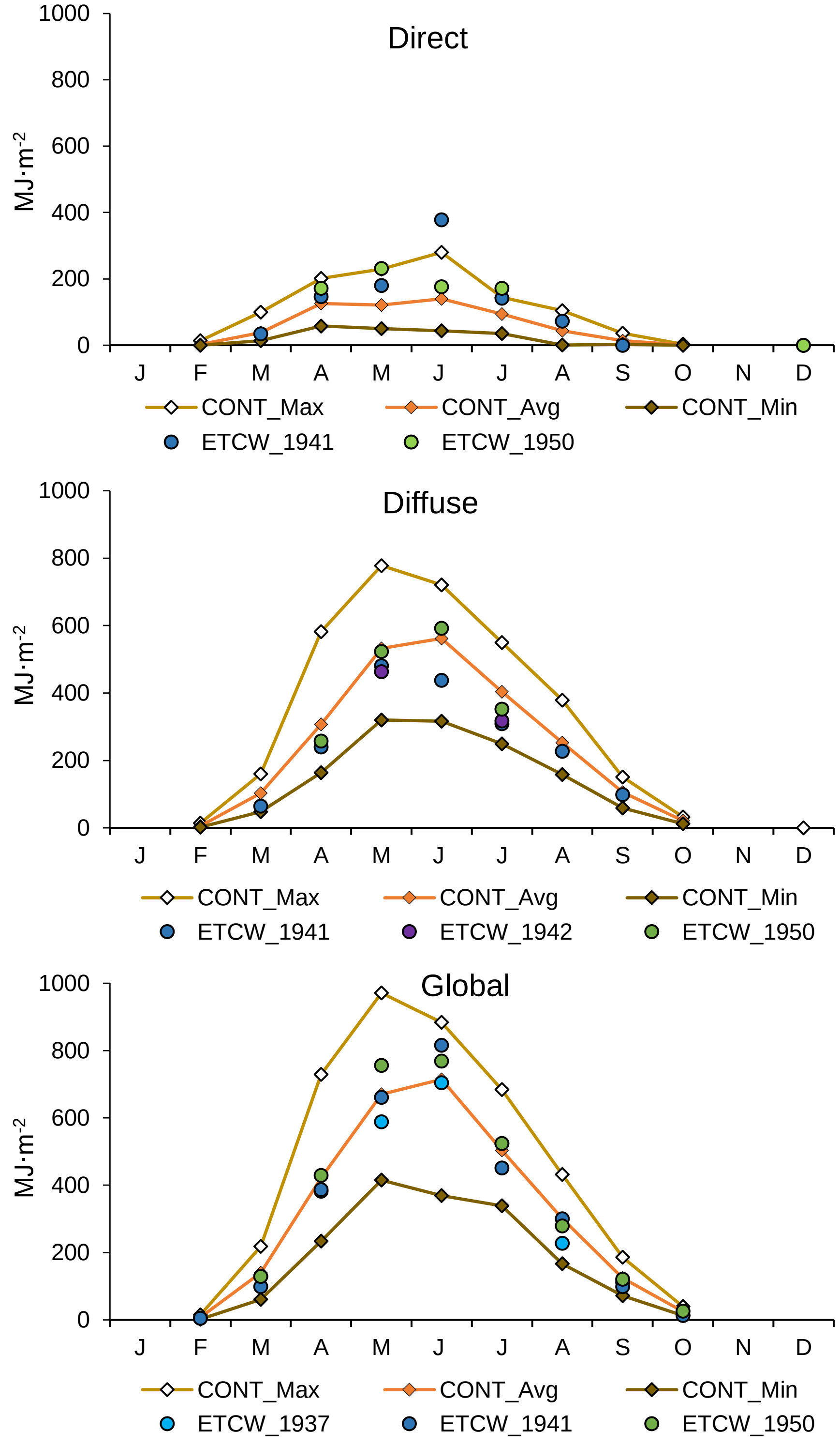


Fig. S9. Highest (CONT_Max), average (CONT_Avg) and lowest (CONT_Min) monthly totals of direct, diffuse, and global solar radiation in contemporary period (2001-19) and individual monthly totals available for three years (ETCW_1937, ETCW_1941 and ETCW_1950) from the ETCW in Mys Cheluskin (Russian Arctic)

Table S1. List of sites (or areas) where solar radiation measurements during Arctic expeditions were taken before the mid-20th century (including the ETCW period, 1921–50)

No.	Site/Area	Period	Elements	Instruments/units	Resolu-tion of available data	Source of data or metadata	Remarks
1	Canadian Arctic, Beaufort Sea	1825–1827	radiation intensity	black and white thermometers	f	Franklin J., 1828: Narrative of a second expedition to the Polar Sea in the years 1825, 1826 and 1827. John Murray, London.	
2	Polaris Bay (φ = 81°36'N, λ = 62°15'W), East Greenland	4.03–21.06 1872	radiation intensity	black and white thermometers	f	Scientific results of the U.S. Arctic expedition. Steamer "Polaries", C.F. Hall commanding, 1876: vol. I. Physical observations, Washington	Bessels was first to noted that in the Arctic, an increase in solar radiation is observed with increase in latitude. Terrestrial radiation was also measured.
3	Polaris House (φ = 78°18'N, λ = 70°15'W), East Greenland						
4	Treurenberg Bay, Spitsbergen (φ = 79°55'1 N, λ = 16°51'5 E)	5–28.09. 1899, 5.04–19.07. 1900	I	Ångström pyrheliometer/ cal per square cm in a minute	f	Westman J., 1903: Mesures de l'intensité de la radiation solaire faites en 1899 et en 1900 à la station d'hivernage suédoise à la baie de Treurenberg. Spitzberg. Miss. Scient. Pour la mesure d'un arc de	First instrumental solar radiation measurements in the Arctic.

						méridien au Spitzberg enterprises en 1899-1902. Vol. II, sec. VIII-e, B. Radiation Solaire, Stockholm.	
5	Arkhangelsk, White Sea	19.06–11.07.1920	I, D	Michelson actinometer No. 5105, Savinov actinometer (“shakhmatny”), instruments calibrated with Ångström pyrheliometer in Pavlovsk Observatory before and after expedition, cal per square cm	f	Kalitin N.N., 1921: Radiation and polarimetric observations conducted in the town of Arkhangelsk and in the White Sea in the summer of 1920, Meteorol. Vestn, Nos. 1–12 (in Russian).	
6	Arkhangelsk (φ = 64°33'N, λ = 40°32'E)	12–20.08.1921	I, D	Ångström pyrheliometer No 79, two Michelson actinometers Nos 5113 and 5105, Savinoff actinometer, Actinograph/ cal per square cm	f, h, d	Kalitin N.N., 1924: Radiation, polarimetric and cloud observations conducted in August and September 1921 by the Hydrographic Expedition of the Arctic Ocean, Zap. po Gidrografii, 48, 153-193 (in Russian).	
7	Tchernoy city, Novaya Zemlya (φ = 70°44'N, λ = 54°35'E)	25–27.08.1921					
8	Karskiye Vorota (Ostrov Vaygatch), φ = 70˚25'N, λ = 58˚40'E	29.08–24.09.1921					

9	East Siberian Sea, Maud Expedition	1922–1925	Q		f, d	Mosby H., 1932: Sunshine and radiation. The Norwegian North Polar Expedition with the "Maud" 1918-1925, Scient. Res., 1a, 7, Geofysisk Institutt, Bergen, 110 pp. Sverdrup H.U., 1933: The Norwegian North Polar Expedition with the "Maud" 1918-1925, Scientific Results, vol. 2, Meteorology, Part 1, Discussion, Geofysisk Institutt, Bergen, 331 pp.	
10	Matochkin Shar, Novaya Zemlya (φ = 73°15'N, λ = 56°23'E, H = 45 m a.s.l.)	21.08–21.09.1923 (G and D until 6.09)	Q, D, I	Savinov pyranometer, Michelson actinometer No 5113, both instruments calibrated in Sluck Magn.-Meteo. Observatory before expedition/ cal per square cm	f, h	Kalitin N.N., 1929: 'Some data on the incoming and outgoing of radiant energy for Matochkin Shar', Izv. GGO, 4, 43-47 (in Russian).	77 series of I, also measured outgoing earth radiation

11	Steamer "Persey", Barents Sea, Novaya Zemlya, northern part in bays Krestovaya and Mashiginaya, Gorbovye islands (around φ = 74°10'N, λ = 55°17'E)	20.08–7.09.1926	I	Khvolson actinometer/ cal per square cm	f	Samoylenko V.S., 1929: Actinometrical observations in the Barents Sea and Novaya Zemlya, Trudy Morsk. Nauchn. Inst., 4 (2), 39-43 (in Russian)	90 series of I
12	Greenland, trip on inland ice (around φ = 66°57'N, λ = 53°23'W)	13–20.08.1927	I	Moll-type thermoelectric pyrheliometer/ gram calories per square cm of horizontal surface, the pyrheliometer was carefully standardised at the United States Weather Bureau	f	Kimball H., 1931: Solar radiation intensities within the Arctic circle, Monthly Weather Review, 59, 4. 154-157.	Pyrheliometric readings made by Prof. J.E. Church, jr., member of the University of Michigan Greenland Expedition
13	Mount Evans, Greenland (φ = 66˚51'N, λ = 50˚50'W, H = 374 m a.s.l.)	6.09.1927–17.04.1928	I	Moll-type thermoelectric pyrheliometer/gram calories per square cm of horizontal surface, the pyrheliometer was carefully standardised at	f	Kimball H., 1931: Solar radiation intensities within the Arctic circle, Monthly Weather Review, 59, 4. 154–157.	These measurements were made by C.R. Kallquist, member of the University of Michigan Greenland Expedition

				the United States Weather Bureau			
14	Green Harbour, Spitzbergen, φ = 78˚00'N, λ = 14˚05'E	4.09.1927–6.08.1928	Q, I	Gorczyński recording solarimeter/ gram calories per square cm of horizontal surface	f, d	Kimball H., 1931: Solar radiation intensities within the Arctic circle, Monthly Weather Review, 59, 4. 154–157.	Installed by Dr. H.U. Sverdrup
15	Chukchi Sea (11 series), area: 70°37'N – 71°21'N and 168°31'E – 174°48'E	13.08–3.09.1929	Q, D	Pyranometer of Kalitin system, calibrated before and after expedition with Ångström pyranometer No. 29 in Sluck Magn.-Meteo. Observatory/ cal per square cm	f, d	Berezkin V.A., 1929: Actinometrical observations in the area of Vrangel Island in August 1929, Meteorol. Vestnik, 9–12, 233–245 (in Russian).	Expedition on the Fedor Litke Ship
16	Vrangel Island (φ = 71˚14'N, λ = 179˚25'W), coast of Rogers Bay (5 series)	13.08–3.09.1929					
17	Chukotka Peninsula, Bukhta Provideniya (φ = 64˚25'N, λ = 173˚15'W)	16.09.1929					
18	Kings Bay, Spitsbergen (φ = 78˚55'N, λ = 11˚56'E)	1929	I?		f?	Götz F.W.P., 1931: Zum Strahlungsklima des Spitzbergensommers: Strahlungs- und Ozonmessungen in der Köningsbucht 1929, Beitr.	Ozone measurements

						zur Geophysik, Bd. 31 (H. 1/3), 119-154 .	
19	West Greenland (West station and Umanak Station, φ = 70˚40'N, λ = 52˚07'W)	1929 and 1930-1931	Q, I		h	Georgi J., 1935: Die Eismittestation. Deutsche Grönland-Expedition A. Wegener 1929 und 1930-31, Wiss. Ergebnisse, 4, 1, Leipzig. Holzapfel R., 1935: Die weststation und die Station Umanak. Deutsche Grönland-Expedition A. Wegener 1929 und 1930-31, Wiss. Ergebnisse, 4, 1, Leipzig. Kopp W., 1939: Diskussion der Ergebnisse der Oststation in Scoresbysund. Deutsche Grönland-Expedition A. Wegener 1929 und 1930-31, Wiss. Ergebnisse, Bd. 4, Hf. 2, Leipzig; Wegener K., 1939: 'Ergünzungen für Eismitte. Deutsche Grönland-Expedition A. Wegener 1929 und 1930-31', Wiss.	
20	Central Greenland (Eismitte Station, φ = 71˚10'N, λ = 39˚56'W)						
21	East Greenland (East Station in Scoresbysund, φ = 70˚29'N, λ = 23˚21'W)	5.08–27.10.1930 and 25.02–6.08. 1931		Linke actinometer, Robitzsch-type actinograph, $cal \cdot cm^{-2} \cdot min^{-1}$			

						Ergebnisse, Bd. 4, Hf. 2, Leipzig.	
22	Sveanor, Spitsbergen (φ = 79°56'5 N, λ = 18°18'E)	2.07–10.08.1931	Q	Robitzsch-type actinograph delivered by Fuess, calibrated with Michelson actinometer 529 and Ångström recording pyranometer No. 40, gram calories per square cm	h, d	Ångström A., 1933: On the total radiation from the Sun and Sky at Sveanor (79˚56’5 N, 18˚18’E), in: Scientific results of the Swedish–Norwegian Arctic Expedition in the summer of 1931, part VII, Geografiska Annaler, 147–156.	Data in Table 1
23	Coppermine (φ = 67°49'N, λ = 115°05'W)	1.09–20.11.1932, 15.01–25.08.1933	Q, SD	Campbell-Stokes sunshine recorder, Robitzsch-type actinograph	d (Q), h (SD)	Canadian Polar Year Expeditions 1932-1933, 1940: Meteorology: Cape Hope’s Advance, Chesterfield Inlet, Coppermine, Meanook, vol. 1, Dominion of Canada, J.O. Patenaude, I.S.O., Printer to the King's Most Excellent Majesty, Ottawa.	
24	Chesterfield Inlet (φ = 63°20'N, λ = 90°42'W)	Q (1.09.1932–31.08.1933), SD (20.08.1932–10.09.1933)	Q, SD	Campbell-Stokes sunshine recorder, Robitzsch-type actinograph	d (Q), h (SD)	Canadian Polar Year Expeditions 1932-1933, 1940: Meteorology: Cape Hope’s Advance, Chesterfield Inlet,	

						Coppermine, Meanook, vol. 1, Dominion of Canada, J.O. Patenaude, I.S.O., Printer to the King's Most Excellent Majesty, Ottawa.	
25	Cape Hope's Advance (φ = 61°05.2'N, λ = 69°33.4'W)	03.08.1932–30.09.1933	SD	Campbell-Stokes sunshine recorder	h	Canadian Polar Year Expeditions 1932-1933, 1940: Meteorology: Cape Hope's Advance, Chesterfield Inlet, Coppermine, Meanook, vol. 1, Dominion of Canada, J.O. Patenaude, I.S.O., Printer to the King's Most Excellent Majesty, Ottawa.	
26	Mount Nordenskiöld, Spitsbergen (φ = 78°10'8 N, λ = 15°26'4 E, H = 1049 m a.s.l.)	01.08.1932-01.09.1933	SD	Campbell-Stokes sunshine recorder, Ångström compensation No 46 pyrgeometer	h, d	Olsson H., 1936a: Sunshine and radiation. Mount Nordenskiöld, Spitsbergen, Geografiska Annaler, XVIII, H. 1, 93–118.	No SD measurements from 1st Nov. to 15th Feb. (polar night), effective outgoing radiation was measured during the polar night
27	Isachsen's Plateau, Spitsbergen (φ = 79°09'N, λ = 12°56'E, H = 850 m a.s.l.)	26.06–15.08.1934	Q, D, I, SD	Robitzsch- type, actinograph controlled with Ångström pyranometer, which was	h, d	Olsson H., 1936b: Radiation measurements on Isachsen's Plateau, in: Scientific results of the Norwegian-Swedish Spitzbergen Expedition in	SD based upon visual observations, measurements of albedo of the snow surface and

				compared often with Michelson actinometer/ gram calories per square cm		1934, part VIII, Geografiska Annaler, 225–244.	absorptions of radiation in snow
28	Chukchi Sea	August 1935	I	Michelson actinometer	f	Piotrovitch V.V., 1936: Short results of hydrophysical observations on board l/k Krasin. Sb. Naucznye rezultaty ekspediciy na l/k "Krasin" w 1935 g., Izd. Glawsewmorputi, Leningrad (in Russian).	
29	West Greenland, Sukkertoppen Ice Cap (φ = 79°09'N, λ = 12°56'W)	summer 1938	Q	Robitzsch-type actinograph?	h, d?	Ruthe K., 1941: Die Grönland Expedition der Universität Oxford, 1928. Polarforschung, Jahrgang 11, Hf. 1, June 30 K., Sugden J.C., Mott P.G., 1940, Oxford University Greenland expedition, 1938. The Geogr. Journ, vol. XCV, No. 1.	Oxford University Greenland Expedition – 1938, meteorological station was established, J.C. Sugden – head of the expedition, more info: https://www.youtube.com/watch?v=nHDgkigy2CY
30	Fröya Glacier, NE Greenland (φ = 74°16'N, λ = 21°00'W)	31 July 1939/40 ??	Q	Robitzsch-type actinograph, controlled by the Ångström actinometer, calibrated before	h, d	Eriksson B.E., 1942: Meteorological records and the ablation on the Fröya Glacier in relation to radiation and meteorological conditions,	31st July meteorological station was established at the base camp located

				expedition in Stockholm using Michelson actinometer		Geogr. Ann., Arg. XXIV, Hf. 1–2.	on the north side of Clavering Island
31	Arctic Ocean near North Pole (φ = 81°29'N, λ = 179°13'E)	April 1941	Q, D	Yanishevskiy pyranometer	f, h	Chernigovskiy N.T., 1946: Actinometrical observations. Aircraft expedition "USSR-N-169" to the Pole of Inaccessibility. Izd. Glawsewmorputi, Moskva- Leningrad (in Russian).	133 series of observations were taken of Q and 55 series of D
32	Vrangel Island	24.03.194– 03.05.1941	Q	Yanishevskiy pyranometer	f, d	Chernigovskiy N.T., 1948: Observations of global solar radiation in Vrangel Island, Probl. Arktiki, 2 (in Russian).	

Explanations: I – direct, D – diffuse, Q – global, SD – sunshine duration. Daily Resolution: f – fixed (sub-daily data, measurements in only a few selected hours), h – hourly, d – daily m – monthly

Table S2. List of actinometrical stations with continuous measurements of solar radiation during the ETCW period, 1921–50

No. *	Name of station	Latitude (N)	Longitude (E)	Height (m a.s.l.)	ETCW period (year, months)	Resolution (h – hourly, f – fixed, m – monthly)	Radiation type (I – direct, D – diffuse, Q – global)	Source of data
33	Matochkin Shar	73°16’	56°24’	18.5	1931 9–11	f	D, Q	AARI Tables TM-12, TM 13
					1932 2–9			
34	Bukhta Tikhaya	80°19’	52°48’	12	1933 10	h, f	D, Q	AARI Tables TM-12, TM 13 Cher 1 and Cher 2
					1934 3–9	h, f	I	
					1934 2–8	h, f	D, Q	
					4–10	m	D, Q	
					1935 3–10	h, f	I	
					1935 9–10	h, f	D, Q	
					3–8	m	D, Q	
					1936 3–9	h, f	I	
					3–8	m	I, D, Q	
					1936 2–8	h, f	D, Q	
					1937 3–10	h, f	I	
					3–8	m	I	
					2–10	h, f	D, Q	
					1938 4–8	h, f	I, D, Q	
					1940 10	h, f	D, Q	
					1941 3–9	h, f	I	
					3–8	m	I, Q	
					3–8	h, f	D, Q	
					1942 1–7	h, f	I	
					3–7	m	I, Q	
35	Ostrov Uedineniya	77°30’	82°14’	9.7	1934 9–11	h, f	I, D, Q	AARI Tables TM-12, TM 13 Cher 1 and Cher 2
					1935 2–8	h, f	I, D, Q	
					2–7	m	Q	
					1936 2–11	h, f	I, D, Q	
					10	m	Q	
					1937 1–12	h, f	I, D, Q	
					2–6	m	Q	
					9–10	m	I, D, Q	
					1938 1–8	h, f	I, D, Q	
					2–7	m	I, D, Q	
					1939 9–10	h, f	I, D, Q	
					9–10	m	Q	
					1940 3–12	h, f	I, D, Q	
					2–10	m	I, D, Q	
					1941 1–7	h, f	I, D, Q	
					2–7	m	I, D, Q	
					1946 10–12	h, f	I, D, Q	
					1947 2–12	h, f	I, D, Q	
					2–10	m	Q	
					1948 1–12	h, f	I, D, Q	
					2–10	m	Q	
					1949 1–12	h, f	I, D, Q	
					2–10	m	Q	
					1950 1–12	h, f	I, D, Q	
					2–10	m	Q	
36	Bukhta Tiksi	71°35’	128°55’	6	1935 8–12	h, f	I, D, Q	AARI Tables TM-12, TM 13 Cher 1 and Cher 2
					9–11	m		
					1936 1–12	h, f		
					2–11	m		
					1937 1–12	h, f		
					1–11	m		
					1938 3–12	h, f		
					4–11	m		
					1939 1–12	h, f		
					2–11	m		
					1940 2–11	m		
					1941 2–7	m		
37	Mys Shmidta	68°55’	179°25’W	6,5	1935 8–12	h, f	I, D, Q	AARI Tables TM-12, TM 13
					1936 1–12	h, f	I, D	
					10–11	m	Q	

					1937 1–12 2–11 2–7 1938 1–12 8–11 1939 1–12 2 3 5 9–11 2–5 8–11 1940 1–12 1–11 1941 1–12 1–10 1942 3–11 7–11 4–11 1943 1–8 3–6 1946 10–12 1–11 1947 1–12 1–11 1948 1–12 1–11 1949 1–12 2–11 1950 1–12 1–11	h, f m m h, f m h, f m m h, f m h, f m h, f m m h, f m h, f m h, f m h, f m h, f m h, f m	I, D, Q I, D Q I, D, Q Q I, D, Q I, D Q I, D, Q I, D, Q I, D, Q I, D, Q I, D, Q I, D Q I, D, Q Q I, D, Q Q I, D, Q I, D, Q I, D, Q I, D, Q I, D, Q I, D, Q I, D, Q I, D, Q	Cher 1 and Cher 2
38	Mys Chelyuskin	77°43’	104°17’	16	1936 9–11 1937 2–10 2–9 1940 10–12 1941 1–12 3–9 2–10 1942 1–4 9–12 5–7 1943 1–3 1949 10–12 1950 12 4–7 3–10	h, f h, f m h, f h, f m m h, f m h, f h, f h, f m m	D, Q D, Q Q D, Q I, D, Q I, D Q D, Q D, Q I, D, Q I, D, Q I, D, Q I, D Q	AARI Tables TM-12, TM-13 Cher 1 and Cher 2
39	Mys Zhelaniya	76°56’	68°58’	7.5	1937 3–8 2–10	m m	D Q	Cher 2
40	Ostrov Dikson	73°30’	80°24’	20	1937 9–10 1938 2–11 1939 2–11 2–10 1940 1–11 2–10 1941 1–11 2–10 1942 2–12 2–10 1943 1–12 2–10 1944 1–11 2–10 1945 1–11 2–10 1946 2–11 2–10 1947 1–9 2–10 1948 1–10 2–10 1949 2–12 2–6 1950 1–12 2–10	h, f, m h, f h, f m h, f m h, f m h, f m h, f m h, f m h, f m h, f m h, f m h, f m h, f m h, f m	I, D, Q	AARI Tables TM-12, TM-13 Cher 1 and Cher 2
41	Ostrov Moustakh	71°33’	130°02’	1	1945 5–8 6–9 1946 2–8 2–8 2–5 8–11 1947 8–11	h m h m m h	I Q I I Q I	AARI Tables TM-12, TM-13 Cher 1 and Cher 2

					8–11	m	I	
					2–11	m	Q	
					1948 1–11	h	I	
					2–10	m	I	
					2–11	m	Q	
					1949 1–10	h	I	
					2–9	m	I	
					2–11	m	Q	
					1950 12	h	Q	
42	Ostrov Rudolfa	81°48'	58°00'	47	1949 3–10 1950 3–6	f	I, D, Q	AARI Tables TM-12, TM-13

Key: * Numbering of the stations as in Figure 1
AARI – Arctic and Antarctic Research Institute
TM-12 – means the Meteorological Table, type 12. This table contains measurements of solar radiation (total, diffuse, direct) for each observation period every day for a month.
TM-13 – means the Meteorological Table, type 13. The table contains measurements of hourly sums of total solar radiation.
All observations are contained in tables, i.e. on paper and most are handwritten.
Cher 1 – Chernigovskiy N.T., 1961a
Cher 2 – Chernigovskiy N.T., 1961b
f – fixed – means sub-daily data (measurements in only a few selected hours)