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New precipitation and accumulation maps for Greenland

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ABSTRACT. Annual total precipitation and the annual accumulation on the Greenland ice sheet are evaluated and presented in two maps. The maps are based on accumulation measurements of 251 pits and cores obtained from the upper accumulation zone and precipitation measurements made at 35 meteorological stations in the coastal region. To construct the accumulation map, the annual precipitation was split into solid and liquid precipitation components. Annual total precipitation exceeding 2500 mm w.e. occurs on the southeastern tip of Greenland, while the minimum precipitation is estimated to occur on the northeastern slope of the ice sheet. The mean annual precipitation for all of Greenland is 340 mm w.e. The largest annual accumulation of about 1500 mm w.e. is found on the glaciers in the southeastern corner of Greenland, while the smallest accumulation is found on the northeastern slope of the ice sheet west of Danmarkshavn. The mean accumulation on the Greenland ice sheet is estimated at 310 mm w.e. The regional difference in accumulation is examined with respect to the 850 hPa (mbar) level circulation. The present surface topography is found to play an important role in determining regional accumulation on the ice sheet.

INTRODUCTION

Accurate information on precipitation and accumulation is an essential prerequisite for understanding the hydrological cycle as well as glacier dynamics. These are also important quantities for estimating future changes of the ice sheet and the sea level, as the greenhouse-induced climatic change takes place. There have already been several attempts to chart the distribution of the annual accumulation of the Greenland ice sheet (Diamond, 1958; Bader,1961; Benson, 1962; Mock, 1967). It is, however, worthwhile constructing a new map, because of the recent increase in information from ice cores on the ice sheet and the meteorological data in the coastal regions. For constructing the accumulation map, a special effort was made to obtain solid precipitation data for the coastal stations, which are necessary for calculating the winter accumulation for the lower regions of the ice sheet and glaciers. To assist in the use of the maps, digital information is provided in tables. The present results will be used for estimating the mass balance of the Greenland ice sheet, which will be reported in the near future.

GLACIOLOGICAL AND METEOROLOGICAL DATA

The basic information on the pits and cores is presented in Table 1. Altogether, 251 pits and cores are used to calculate the distribution of the annual accumulation on the ice sheet. There are more accumulation data, especially from earlier expeditions, but they are considered to be either too short in terms of the time duration or contaminated by the melt, and thus have been excluded from the present analysis. The period for which the data are used encompasses 77 years from 1913 (de Quervain and Mercanton, 1920; Koch and Wegener, 1930) to 1989 (personal communication from F. Nishio). The precipitation data at coastal sites were collected at 35 meteorological stations and are presented in Table 2. The meteorological data are from the following sources: the Danish Meteorological Institute (1954–62, 1969, 1969–82), ESSA (1968), NOAA (1987), and unpublished precipitation data in the archives of the Danish Meteorological Institute. The Canadian meteorological data were obtained from Hare and Thomas (1974) and Ohmura (1977). The data for Søndre Strømfjord were obtained

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Table 1. Annual accumulation at Greenland ice-sheet stations

Reference	Station	Coordinates °′N,	°′W	Altitude m	Accumulation mm w.e.
Ambach	CARREFOUR	69 50	47 26	1849	570
Benson	00–10	76 25	67 44	864	300
Benson	0–60 1–0	76 44	65 24	1310	650
Benson	1–10	76 49	64 54	1418	400
Benson	1–20	76 54	64 24	1486	330
Benson	1–30	76 59	63 54	1519	250
Benson	1–40	77 04	63 23	1570	230
Benson	1–50	77 09	62 54	1630	230
Benson	1A–10	77 02	62 22	1720	350
Benson	1A–20	76 56	62 00	1660	450
Benson	1–60 2–0	77 15	62 20	1704	210
Benson	2–10	77 14	61 38	1788	250
Benson	2–20	77 14	61 02	1834	300
Benson	2–30	77 12	60 24	1887	380
Benson	2–40	77 11	59 45	1885	400
Benson	2–50	77 10	59 05	1877	405
Benson	2–60	77 09	58 27	1905	390
Benson	2-70	77 07	57 50	1919	400
Benson	2–80	77 04	57 13	1944	400
Benson	2–90	77 02	56 54	1959	410
Benson	2–100	77 04	56 07	1992	400
Benson	2–120	77 12	55 46	2140	320
Benson	2–125	77 03	54 31	2152	320
Benson	2–150	77 04	52 56	2273	270
Benson	2–175	77 04	51 20	2392	240
Benson	2–200	77 11	49 47	2458	220
Benson	2–225	77 04	48 01	2536	185
Benson	2–250 4–0	76 58	46 60	2616	165
Benson	4–25	76 39	45 43	2674	175
Benson	4–50	76 19	45 06	2720	175
Benson	4–75	75 60	44 35	2749	185
Benson	4–100	75 39	43 58	2778	190
Benson	4–125	75 18	43 26	2821	205
Benson	4–150	74 57	42 59	2851	210
Benson	4–175	74 36	42 33	2873	220
Benson	4–200	74 14	42 11	2918	230
Benson	4–225	73 53	41 48	2940	230
Benson	4–250	73 32	41 26	2972	230
Benson	4–275	73 10	41 06	3003	250
Benson	4–300	72 49	40 46	3046	270
Benson	4–325	72 29	40 20	3104	285
Benson	4–350	72 08	39 57	3128	290
Benson	4–375	71 47	39 36	3131	295
Benson	4–400	71 26	39 20	3126	305
Benson	4–425 5–0	71 06	38 59	3123	305
Benson	5–20	71 00	39 41	3072	335
Benson	5–40	70 55	40 39	3005	355
Benson	5–65	70 47	41 39	2882	400
Benson	5–90	70 38	42 37	2763	450
Benson	5–115	70 28	43 35	2646	470
Benson	5–140	70 19	44 33	2466	510
Benson	5–150	70 16	44 59	2407	540
Benson	5–160	70 11	45 22	2342	530
Benson	5–170	70 07	45 45	2283	550
Benson	5–180	70 03	46 09	2206	550
Benson	5–190	69 59	46 31	2146	550
Benson	5–200	69 55	46 57	2012	600
Benson	5–210	69 53	47 18	1963	580
Benson	5–220	69 49	47 41	1861	560
Benson	5–230	69 44	48 03	1746	540
GISP	DYE3-P	65 12	43 47	2465	541
GISP	OHIO 13B	65 06	44 14	2560	440
GISP	CC UPSTREAM	77 14	60 49	1910	348
GISP	CC DRILLCMP	77 12	61 05	1880	348
GISP	NORTH CENTRL	74 38	39 37	2931	132
GISP	SUMMIT	72 18	37 59	3214	240
GISP	CRETE T43	71 08	37 19	3172	273
GISP	NORTH SITE	75 47	42 27	2852	151
GISP	MILCENT	70 19	44 35	2410	486
GISP	SITE DIVIDE	65 03	44 00	2620	392
GISP	OHIO 1001	65 24	47 41	1992	382
GISP	OHIO 1002	65 24	47 15	2134	374
GISP	OHIO 1005	65 24	48 07	1832	554
GISP	OHIO 2001	65 07	45 42	2486	367
GISP	OHIO 2002	65 05	45 18	2548	335
GISP	OHIO 2005	65 09	46 07	2409	362
GISP	OHIO 3005	65 08	44 12	2553	443
GISP	OHIO 3007	65 01	44 39	2626	373
GISP	A/1985	70 39	35 50	3092	282
GISP	B/1985	70 40	37 29	3138	300
GISP	C/1985	70 41	38 48	3072	312
GISP	D/1985	70 39	39 38	3018	335
GISP	E/1985	71 46	35 52	3087	206
GISP	F/1985	71 30	35 53	3092	217
GISP	G/1985	71 10	35 51	3098	230
GISP	H/1985	70 52	35 51	3102	254
GISP	A1–S2	67 49	42 55	2460	333
GISP	A1	67 28	41 59	2546	479
GISP	A1–S1	67 00	41 39	2470	587
GISP	DYE-2	66 29	46 20	2100	343
GISP	SNS–1	66 29	44 50	2340	359
GISP	SN	66 12	43 40	2504	580
GISP	SNS–2	65 55	42 44	2300	680
GISP	SDS–3	65 51	44 07	2510	558
GISP	SDS–1	65 42	44 46	2480	428
GISP	SAS	65 41	44 19	2507	526
GISP	SDS–2	65 32	44 07	2490	520
GISP	P36	64 57	45 04	2630	390
GISP	P20	65 05	44 26	2610	380
GISP	D2	65 10	43 49	2516	462
GISP	D3	65 11	43 49	2499	471
GISP	D4	65 11	43 49	2495	500
GISP	D5	65 11	43 49	2502	491
GISP	D6	65 11	43 50	2499	481
GISP	ST1	65 11	43 50	2484	517
GISP	BDS	64 31	44 20	2730	445
GISP	DS–3	63 43	44 32	2820	451
GISP	DS–2	63 33	44 57	2800	391
GISP	SD	63 33	44 36	2831	486
GISP	DS–1	63 36	44 16	2820	600
Hamilton	Northice	78 04	38 29	2345	90
Hendrickson 66 17		47 46	1792	317	
Koch-Wegener		75 59	30 43	2310	159
Koch-Wegener		75 46	32 44	2241	148
Koch-Wegener		75 42	33 18	2513	112
Koch-Wegener		75 34	34 05	2570	225
Koch-Wegener		75 31	34 33	2582	210
Koch-Wegener		75 27	35 06	2606	175
Koch-Wegener		75 21	35 29	2629	169
Koch-Wegener		75 17	35 52	2653	152
Koch-Wegener		75 06	37 05	2705	172
Koch-Wegener		75 02	37 30	2712	173
Koch-Wegener		74 59	37 51	2722	169
Koch-Wegener		74 55	38 12	2737	161
Koch-Wegener		74 44	39 28	2807	80
Koch-Wegener		74 40	39 51	2847	123
Koch-Wegener		74 34	40 31	2890	130
Koch-Wegener		74 27	41 11	2918	170
Koch-Wegener		74 23	41 25	2924	174
Koch-Wegener		74 19	41 59	2935	153
Koch-Wegener		74 12	42 32	2933	185
Koch-Wegener		74 08	43 03	2928	237
Koch-Wegener		74 02	43 31	2920	237
Koch-Wegener		73 59	44 16	2909	296
Koch-Wegener		73 53	44 56	2881	290
Koch-Wegener		73 49	45 30	2811	311
Koch-Wegener		73 46	45 48	2752	388
Koch-Wegener		73 44	46 37	2681	589
Koch-Wegener		73 36	47 02	2636	635
Koch-Wegener		73 27	47 40	2547	359
Koch-Wegener		73 19	48 07	2496	387
Koch-Wegener		73 12	48 37	2415	443
Koch-Wegener		73 02	49 18	2284	338
Koch-Wegener		72 55	49 57	2216	420
Koch-Wegener		72 51	50 16	(2120)	375
Koch-Wegener		72 49	50 20	2100	325
Koch-Wegener		72 42	51 19	1850	296
Koch-Wegener		72 36	51 46	1706	230

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Langway 1	77 14	62 20	1718	256
Langway 2	77 44	59 34	2025	202
Langway 3	78 12	56 19	2068	224
Langway 4	78 38	53 00	2096	168
Langway 5	79 02	49 09	2147	159
Langway 6	79 44	51 26	1843	199
Langway 7	80 23	54 03	1524	248
Langway 8	80 46	55 20	1420	265
Langway 9	79 29	44 19	2215	139
Langway 10	80 00	39 39	2071	131
Langway 11	80 40	39 39	1960	174
Langway 12	81 19	39 45	1803	196
Langway	77 59	52 31	2296	159
Langway	78 55	48 13	2205	138
Langway	79 55	43 02	2145	135
Lead dog 0.0	80 00	39 39	2071	115
Lead dog 4	80 02	38 26	2028	120
Lead dog 11	80 02	35 34	1924	139
Lead dog 21	80 00	31 16	1690	201
Merc-Quer 11	68 57	46 45	1831	350
Merc-Quer 12	68 50	46 13	1888	335
Merc-Quer 13	68 42	45 45	1936	265
Merc-Quer 14	68 35	45 17	2046	250
Merc-Quer 15	68 27	44 47	2176	342
Merc-Quer 16	68 16	44 16	2243	524
Merc-Quer 17	68 06	43 49	2318	440
Merc-Quer 18	67 55	43 16	2399	395
Merc-Quer 23	67 04	41 14	2258	201
Merc-Quer 24	66 59	40 53	2254	336
Mock P42–7	77 03	61 24	1819	365
Mock CENTURYASTRO	77 11	61 09	1885	318
Mock P42–11	77 18	61 11	1886	214
Mock P42–13	77 24	61 19	1877	182
Mock P42–15	77 32	61 29	1868	162
Mock P42–17	77 34	61 11	1760	182
Mock P42–19	77 36	62 45	1654	225
Mock P42–21	77 38	63 28	1510	243
Mock S–40	76 40	62 10	1262	603
Mock S–30	76 47	61 54	1553	548
Mock S–20	76 55	61 41	1728	468
Mock-Alf HIRAN 26	68 19	36 21	2925	230
Mock-Alf HIRAN 28	70 38	36 11	3138	230
Mock-Alf HIRAN 29	68 04	42 20	2594	460
Mock-Ragle 59–0	66 35	47 13	1953	300
Mock-Ragle 59–26	66 28	46 15	2150	320
Mock-Ragle 59-46	66 25	45 31	2280	330
Mock-Ragle 59–66	66 19	44 48	2366	330
Mock-Ragle 59–86	66 14	44 09	2460	370
Mock-Ragle 59–190	65 12	43 37	2476	460
Mock-Ragle 59–250	64 29	42 58	2489	770
Mock-Ragle 59–275	64 30	43 50	2700	570
Mock-Ragle 59–300	64 30	44 42	2722	300
Mock-Ragle 59–325	64 29	45 37	2536	320
Mock-Ragle 59–350	64 28	46 35	2373	390
Mock-Ragle 59–375	64 26	47 31	2189	470
Mock-Ragle 59–425	63 44	47 20	2241	410
Mock-Ragle 59–475	63 12	46 19	2598	560
Mock-Ragle 59–525	62 31	46 00	2426	660
Mock-Ragle 59–550	62 13	45 40	2461	720
Mock-Ragle 59–575	62 01	45 02	2435	800
Mock-Ragle 59–600	61 50	44 25	2210	900
Mock-Ragle 60–75	62 31	45 15	2624	560
Mock-Ragle 60–127	63 14	45 04	2759	430
Mock-Ragle 60–270	65 12	43 47	2476	460
Mock-Ragle 60–1–139	66 28	46 15	2142	320
Mock-Ragle 60–1–117	66 17	45 43	2258	390
Mock-Ragle 60–1–96	66 04	45 10	2370	370
Mock-Ragle 60–1–75	65 51	44 37	2473	640
Mock-Ragle 60–1–50	65 34	44 09	2479	770
Mock-Ragle 60–1–00	65 14	43 00	2252	970
Muller D	78 12	71 45	1080	300
Muller F	78 08	71 10	1500	148
Muller V	77 04	70 25	1100	463
Muller VI	76 46	64 35	1560	713
Nishio PRT–1	66 52	46 16	2000	300
Paterson A16	77 29	29 28	1859	130
Paterson A31	77 40	33 15	2096	100
Paterson A58	78 44	40 44	2442	120
Paterson B64	78 02	42 46	2512	150
Paterson A73	78 02	45 37	2516	110
Paterson B9	77 20	27 56	1713	110
Paterson B77	77 14	25 22	1270	140
Paterson B81	77 16	24 28	940	250
Paterson B107	77 40	47 57	2526	120
Paterson A	77 10	48 51	2547	130
Paterson B	76 57	48 05	2603	180
Paterson C	76 44	47 20	2671	140
Paterson D	76 27	46 31	2689	170
Paterson E	76 12	45 46	2742	160
Paterson F	75 59	45 00	2774	200
Paterson H	76 27	43 36	2771	170
Paterson DE 76 34	45 19	2733	180	
Paterson C1	76 53	46 13	2695	170
Paterson C2	77 02	45 09	2664	150
Paterson C3	77 12	44 02	2652	170
Paterson C4	77 23	43 01	2616	160
Quervain K 3	69 40	49 15	1217	220
Quervain CAMP VI	69 45	48 05	1674	266
Quervain MILCENT	70 19	44 35	2448	426
Quervain CENTRAL	70 55	40 39	2960	371
Quervain CRETE	71 08	37 20	3171	289
Quervain J-JOSET	71 22	33 29	2863	258
Quervain DEP420	72 14	32 20	2808	274
Quervain DEP480	72 31	29 59	2371	284

Sources: Ambach Carrefour: Ambach (1977); Benson: Benson (1962); GISP D2–6: Dansgaard and others (1985); GISP OHIO: Whillans (1987); GISP A–H/1985: Clausen and others (1988); all other GISP sites: Radok and others (1982); Hamilton Northice: Hamilton and others (1956); Hendrickson: Schuster (1954); Koch-Wegener: Koch and Wegener (1930); Langway: Langway (1961); Lead dog: U.S. Army Transportation Board (1960); Merc-Quer: de Quervain and Mercanton (1920); Mock: Mock (1965); Mock-Alf: Mock and Alford (1964); Mock: Mock and Ragle (1963) and Ragle and Davis (1962); Müller D. F., V and VI: Müller and others (1977); Paterson: Paterson (1955); Quervain: de Quervain (1969); Nishio: personal communication.

Table 2. Annual total precipitation at meteorological stations in Greenland

Station	*Coordinates*		*Altitude*	*Precipitation*	*Period*
	N,	W	m	mm	
Thule (Kanak)	77 29	69 12	15	104(54)	1956–78 (61,62,63,65, 77 missing)
Dundas	76 34	68 48	21	114(82)	1960–80 (79 missing)
Thule AFB	76 31	68 50	59	113(82)	1951–73 (61, 62,63,65 missing)
Upernavik	72 47	56 10	63	238(162)	1951–80
Umanak	70 40	52 00	40	167(147)	1951–80
Qutdligssat	70 03	52 51	3	202(136)	1961–71
Jakobshavn	69 13	51 03	40	252(142)	1961–80

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Christianshåb	6849	5105	77	261(149)	1962–79
Godhavn	6914	5331	25	420(255)	1931–45, 50–79
Egedesminde	6842	5245	47	300(175)	1951–80
Søndre Strømfjord	6701	5048	55	151(77)	1941–65
Holsteinsborg	6655	5340	9	358(208)	1961–80
Sukkertoppen	6524	5252	24	671 (327)	1961–80
Neriunaq	6428	5024	7	255(130)	1938–60
Godthåb	6410	5145	27	734(432)	1951–80
Faeringehavn	6342	5133	7	739(421)	1961–72
Frederikshåb	6200	4943	16	812(410)	1951–80
Ivigtut	6112	4810	30	1282(637)	1931–65
Narssarssuaq	6111	4525	26	607(283)	1961–80
Igaliko	6059	4530	7	816(410)	1935–46
Julianehåb	6043	4603	29	847(405)	1961–80
Narssaq	6054	4558	31	880(401)	1961–69
Grønnedal	6113	4807	27	1027(502)	1951–70
Nanortalik	6008	4513	21	847(419)	1932–46, 64–80
Nord	8136	1640	35	184(140)	1953–80 (72,73,74,75, 77 missing)
Danmarkshavn	7646	1846	12	139(123)	1951–80
Daneborg	7418	2013	13	214(180)	1961–74
Myggbukta	7329	2134	2	300(246)	1931–39, 46–58
Mesters Vig	7215	2354	10	288(225)	1961–74
Kap Tobin	7025	2158	41	458(379)	1951–80
Aputetiq	6747	3218	19	806(590)	1951–78
Angmagssalik	6536	3734	35	961(731)	1951–79
Tingmiarmiut	6232	4208	10	1477(956)	1951–78
Torgilsbu	6032	4311	24	1930(1255)	1932–40
Prins Christian Sund	6002	4307	76	2471(1480)	1951–79

Values in brackets are solid precipitation.

from the Data Processing Division, ETAC, USAF. The base topographic map is based on the new map of the Greenland ice sheet by Ohmura (1987).

Because the glacier accumulation is used for estimating annual precipitation, it is in order to discuss the difference between the two quantities. The accumulation is the result of precipitation, drifting, and evaporation. Although accumulation and precipitation are different processes, the numerical values are similar for a number of glaciers (Ohmura and others, in press). While the evaporative and drifting loss is often considered to yield an underestimation of precipitation, the measured precipitation is more often smaller than accumulation. One of the reasons for a smaller value of meteorologically measured precipitation is, no doubt, the failure to capture snowflakes by the snow gauge. After investigating the annual precipitation and accumulation for 12 glaciers, for which relatively long-term observations of both quantities are available, Ohmura and others (in press) found that the meteorological precipitation is on average 17% smaller than the glaciologically determined accumulation. Therefore, uncertainty of the order of 20% must be considered inherent in the present results.

COMPARISON WITH PREVIOUS MAPS

The present result for the distribution of accumulation is compared with previously published works which are often quoted in the literature (Fig. 1). They are Bader (1961), Benson (1962), and Mock (1967). The oldest work on this topic by Diamond (1958) is not used in the present comparison as its content is taken into account by Bader (1961), and the mapping therein does not cover the entire ice sheet. In general, qualitative similarities are found between the present work and that of Benson (1961) for southern Greenland and with that of Mock (1967) for northern Greenland. Major improvements in the present work include depicting the belt of higher accumulation at 1500 m a.s.l. on the northwest slope facing Nares Strait; more realistic accumulation data in the ice-cap area south of Inglefield Land; providing the accumulation for the ice cap in Steensby Land; presentation of a more accurate picture of the entire west slope of the ice sheet and the southern ice cap; and especially the correction of previous overestimates for the area of the ice sheet below 2000 m a.s.l. These improvements can mainly be traced to the use of data provided by de Quervain and Mercanton (1920), Langway (1961), de Quervain (1969), Müller and others (1977), Ohmura (1977), and Whillans (1987). For calculating more realistic accumulation for altitudes below 2000 m a.s.l., the separation of the annual precipitation into solid and liquid precipitation for the coastal meteorological data played an important role. Overall, the present work also provides the distribution of precipitation and accumulation in high areal resolution which makes it possible to interpret the precipitation distribution for the Greenland ice sheet from a climatological viewpoint, as is presented in the following section.

RESULTS AND DISCUSSION

The distribution of annual precipitation is shown in Figure 2. The main features of the distribution are summarized as follows: a strong longitudinal gradient exists in southern Greenland, south of 65° N on the west and south of 70° N on the east slopes; within this region the east coast receives considerably more precipitation than the west coast; the largest precipitation is observed in the southernmost region of the east coast; an extensive area with extremely small precipitation is expected on the north-eastern slope of the ice sheet; there are some local peculiarities, such as

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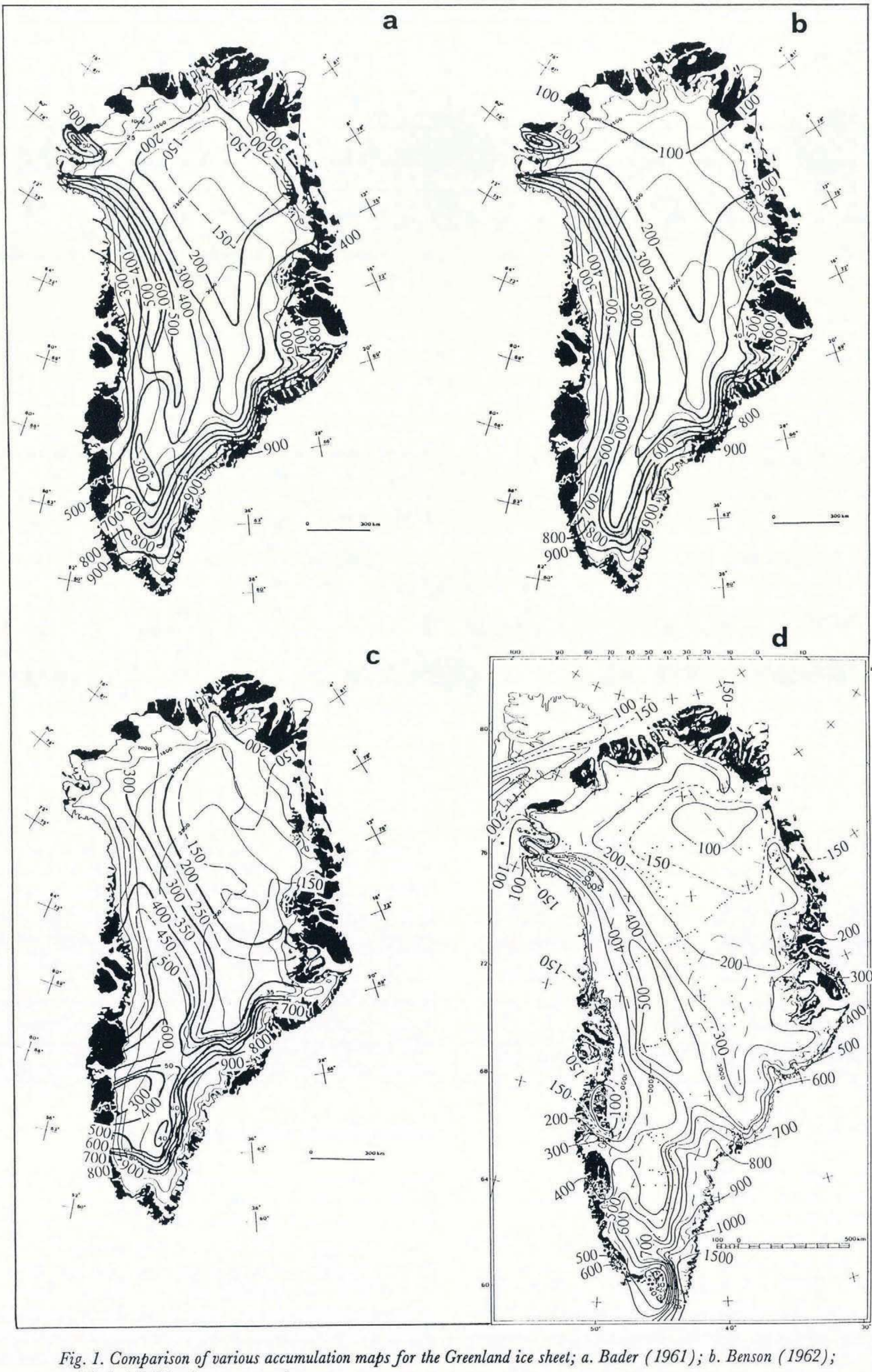

Fig. 1. Comparison of various accumulation maps for the Greenland ice sheet; a. Bader (1961); b. Benson (1962); c. Mock (1967); d. present work.

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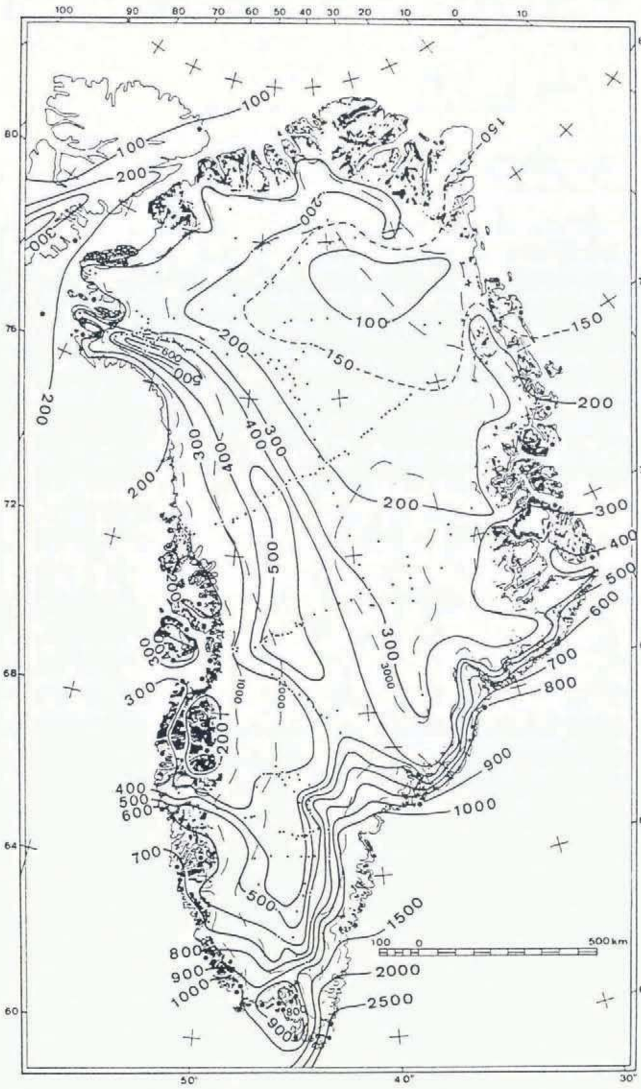

Fig. 2. Annual total precipitation in mm for Greenland. Dots on glaciers are locations of cores and pits. Solid circles are meteorological stations.

the belt of higher precipitation on the middle west slope extending from 69° N at 2400 m a.s.l. to the area north of Melville Bay, where it descends to 1500 m a.s.l.; there are very dry patches around Søndre Strømfjord on the west coast and also around Narssarssuaq in southern Greenland. The mean annual precipitation for all Greenland is 340 mm w.e.

The amount of precipitation is regulated primarily by atmospheric conditions, such as stability, water-vapour content, and circulation, often combined with topography. Climatologically important features of the atmospheric circulation, leading to the regional variation in precipitation, are more clearly depicted in the interplay between the topography and the monthly resultant wind field, rather than on daily synoptic maps. The resultant wind is a vector mean of instantaneous wind over a certain period. Resultant wind calculated thus becomes mathematically identical to the geostrophic wind computed on the time-mean pressure field. The resultant wind is a convenient concept to use to trace the transport of atmospheric constituents, such as water vapour and pollutants.

Monthly resultant wind is calculated for January and July for the level of 850 hPa (mbar) over Greenland. The 850 hPa level is chosen because it is very close to the mean altitude of the Greenland ice sheet of about 1500 m a.s.l. The resultant wind field is calculated with the geostrophic approximation based on the monthly 850 hPa charts by Scherhag (1969) modified with additional radiosonde data provided by the National Climatic Center, NOAA, and by the data archives of the North Water Project at the Eidgenössische Technische Hochschule. The January and July resultant wind fields are expressed in terms of streamlines and are shown in Figures 3 and 4, respectively. The concentration of streamlines is expressed as being proportional to the wind speed.

The winter circulation is strongly dominated by two semi-permanent cyclones, the Baffin Bay low to the west and the larger Icelandic low to the southeast. The Greenland ice sheet is located under a weak saddle between the two depressions. This setting determines the main route of water-vapour flow. The southeast coast is directly hit by the onshore flow from the northern flank of the Icelandic low, with relatively high water-vapour content of 2.1 g m^{-3} from the Atlantic Ocean. This flow causes heavy precipitation on the southeast slope so long as the air mass is forced to ascend along the surface of the ice

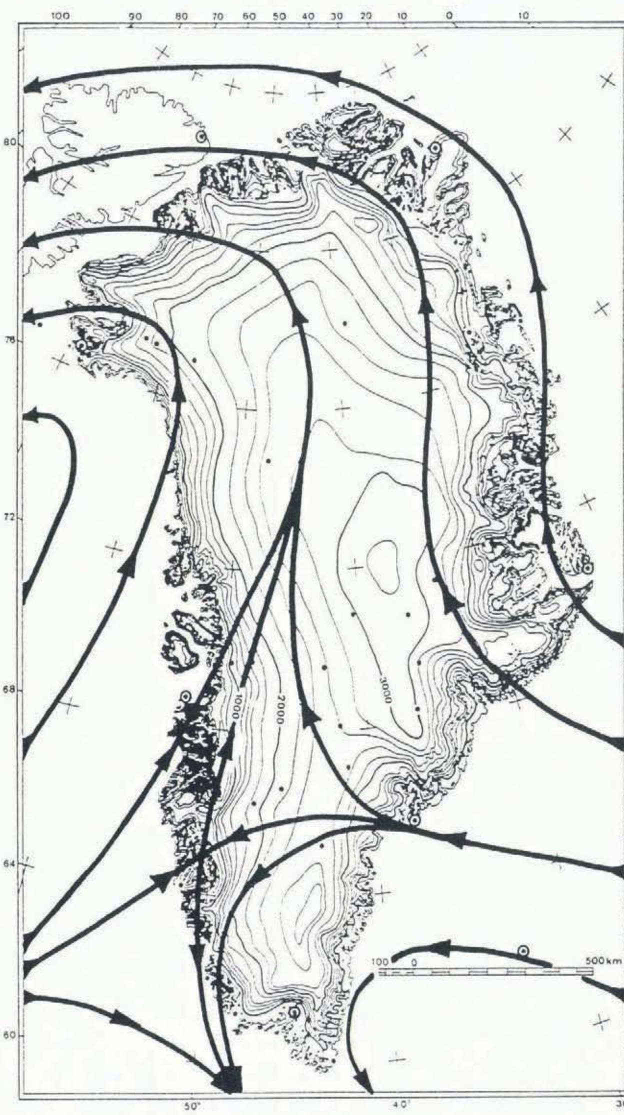

Fig. 3. Monthly resultant wind stream lines at 850 hPa (mbar) for January.

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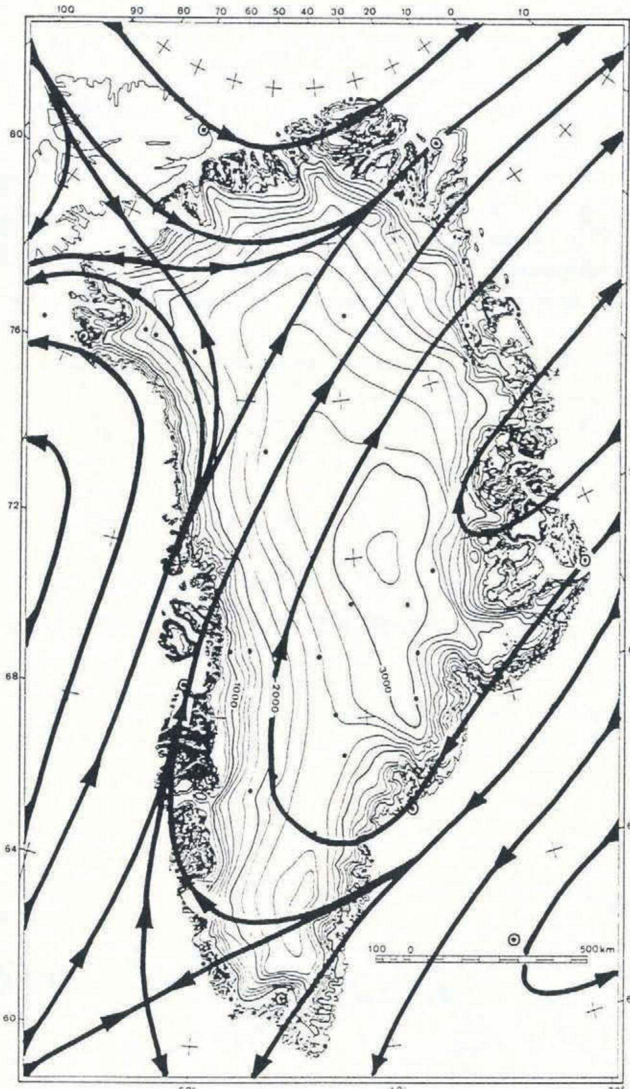

Fig. 4. Monthly resultant wind stream lines at 850 hPa (mbar) for July.

sheet. Once it starts to descend on the vast area north of Summit and on the west slope of the south cap, precipitation will be terminated. The illustration shows that the crest area of the ice sheet is under the influence of the Atlantic Ocean rather than the continental air mass from North America. The area of the west coast, north of 65° N also receives the onshore wind from the southwest. The air mass is originally continental, though modified slightly over Davis Strait and Baffin Bay, and is very dry, i.e. 0.7 g m^{-3} water-vapour concentration, and incapable of causing high precipitation. The winter precipitation on the west coast is caused primarily by migrating cyclones entering Baffin Bay from the Atlantic Ocean through Davis Strait.

The summer ciculation over Greenland is dominated by the pressure ridge extending from the northeast towards the centre of the ice sheet. Both Baffin Bay and Icelandic lows remain in their locations. The Polar basin to the north is covered by another low. On the southeast coast, the precipitation decreases somewhat compared with winter, owing to the shift of the streamlines which now run parallel to the slope. On the other hand, the onshore flow on the west coast is loaded with high water-vapour content (4.5 g m^{-3}) and causes the summer peak of precipitation. The air mass (temperature 3°C, and dew point −1°C) reaches condensation level at an altitude of about 2200 m a.s.l. on the mid-west slope, causing major precipitation above this altitude. During the summer, the northwest slope of the ice sheet, facing Nares Strait, also receives up-slope advection from the west and receives some precipitation. These westerlies are the result of the appearance of the low over the Polar basin. The northeast slope of the ice sheet also remains during the summer in the precipitation shadow, both with respect to the southwesterlies and the westerlies, thus receiving the lowest precipitation on the ice sheet. Likewise, Narssarssuaq receives only one-quarter of the annual precipitation of Prince Christian Sund, 150 km to the southeast but on the other side of the ridge extending from the south ice cap. The region around Søndre Strømfjord is located to the north of a weak ridge on the ice sheet which leads to Sukkertopen Ice Cap to the west. The ridge blocks the southwesterlies year round.

The belt of higher precipiation half-way on the west slope is a natural consequence of the condensation level, as explained in the preceding paragraph and the depletion of water vapour at higher altitude. This is also a common feature in the vertical distribution of precipitation in mountainous regions. This phenomenon is not limited to the area surrounded by 500 mm isolines on the west slope. A close examination of the illustration shows the existence of a maximum precipitation belt all along the northwest to northeast slopes down to Kap Tobin on the mid-east coast. A tendency of the higher precipitation belt to appear is also seen on the west side of the south ice cap. A similar high-precipitation zone does not show up on the southeast slope. This is probably due to the lack of accumulation data between sea level and 2200 m a.s.l. Some pit observations by de Quervain (de Quervain and Mercanton, 1920) above Angmasalik suggest the existence of higher precipitation below 2000 m a.s.l. Owing to partial melt in the snow profile, his data for this altitude are not taken into account. In addition, a steep surface gradient of the ice sheet on the southeast side makes the occurrence of such a phenomenon less conspicuous.

The streamlines in Figures 3 and 4 also suggest that the sites of the deep ice coring, Dye 3 and Summit, are under the influence of the Atlantic air mass during the entire year, while Camp Century is located more under the effect of the continental air mass from North America, modified by Baffin Bay.

Important topographic barriers are shown in Figure 5, together with geographical names used in the present work. These barriers are not necessarily major ridges in terms of altitude, but they play an important role in dividing ice-sheet surfaces, simply due to the way the relative direction of the barrier is directed with respect to the major stream lines of high water-vapour content.

The distribution of the annual accumulation is given in Figure 6. The overall pattern of the accumulation distribution resembles that for annual precipitation, the main difference being the liquid precipitation subtracted from the annual precipitation for the coastal stations. The greatest accumulation, exceeding 1500 mm w.e., is estimated to occur on the east-facing slope of the south ice cap between Kap Cort Adelaer and Prince Christian Sund.

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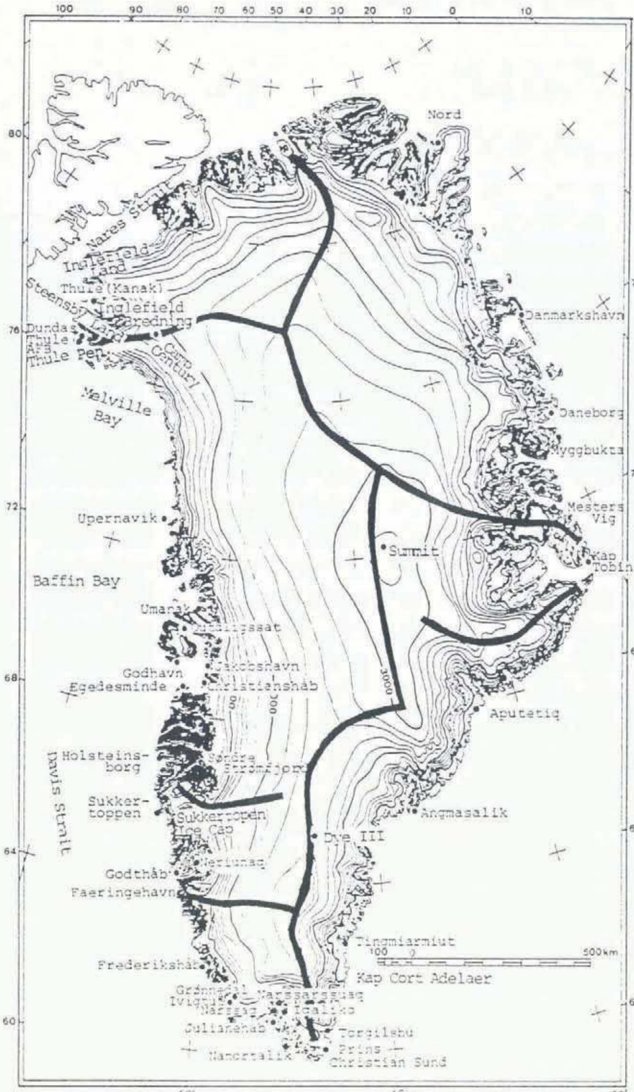

Fig. 5. Important topographic barriers influencing the accumulation on the Greenland ice sheet: geographical names used in the present work are indicated.

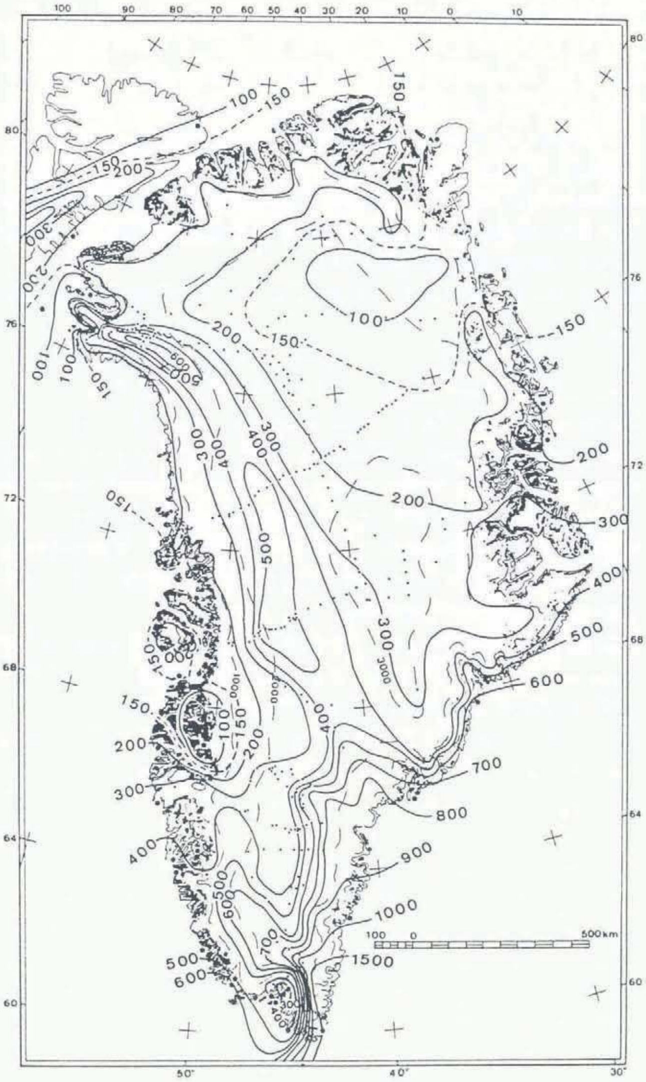

Fig. 6. Annual accumulation and solid precipitation in mm w.e. for Greenland. Dots on glaciers are locations of cores and pits. Solid circles are meteorological stations.

The zone of relatively high accumulation sweeps from the east slope to the west slope along the south slope of the south ice cap at around 2000 m a.s.l. Another zone of higher accumulation is located from the col between the south ice cap and the main ice cap on the west slope towards Thule Peninsula. Within this zone, several locations with especially high accumulation are observed: 550 mm w.e. at 2200 m a.s.l. east of Jakobshavn, 650–700 mm w.e. at 1700 m a.s.l. on the slope facing Melville Bay, 200 km east of Thule AFB. Very low accumulation of less than 100 mm w.e. is found on the northeast slope of the ice sheet and at the lower altitudes less than 800 m a.s.l. east of Søndre Strømfjord. The ablation area of the outlet glaciers around Inglefield Bredning in northwest Greenland is also estimated to have accumulation of less than 100 m.

The mean annual accumulation on the Greenland ice sheet based on the results given in Figure 2, is 310 mm w.e. for the ice-sheet area of 1.676×10^6 km^2. Within this definition of the ice sheet, the ice surfaces included are that of the main ice sheet and those of the ice caps which are connected to the main ice sheet through the accumulation areas. Valley glaciers, isolated ice caps, and the ice caps connected to the main ice sheet only through their ablation areas are excluded. The mean annual accumulation on all glacier surfaces in Greenland (1.75×10^6 km^2) is estimated at 317 mm w.e.

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