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Glacier distribution and direction in the Arctic: the unusual nature of Svalbard

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Local glaciers in the Arctic, as elsewhere, are valuable climatic indicators. On a regional scale (Table 1), their varying ELAs (Equilibrium Line Altitudes) or mid-altitudes reflect the dominant direction of snow-bearing winds. In the Eurasian Arctic, this is mainly from the Atlantic and ELAs rise eastward (Grosval'd and Kotlyakov 1969; Dowdeswell and Hambrey 2002; Dowdeswell and Hagen 2004). Here I will focus on the effects of accumulation area slope aspect on the numbers and altitudes of local glaciers. Local slopes affect several components of glacier mass balance, and we expect that there will be both lower glaciers, and more glaciers, facing directions (azimuths, aspects) with more positive mass balances. North: south contrasts due to solar radiation receipts are great in middle latitudes, especially in dry, sunny climates, but diminish toward the Poles (Evans and Cox 2005).

Analyses of World Glacier Inventory data confirm the expectation that poleward tendencies in both greater numbers and lower altitudes would be weaker for Arctic glaciers, if defined as those regions above 70°N (Evans 2006; Table 2). However, several Arctic regions (Wrangel Island, Svalbard, Ellesmere Island and Axel Heiberg Island) have favoured directions in terms of numbers of glaciers (expressed by vector means) very different from their lowest mid-altitude directions. These anomalous results are unusual and require explanation.

Out of a total 685 glaciers, Novaya Zemlya has 395 valley, 158 mountain glaciers and 27 glacierets, giving 580 local glaciers, 574 of which have the aspect and altitude data for analysis of local asymmetry. The direction of minimum mid-altitude as predicted from the regression on latitude, longitude, sine and cosine of aspect is 098° ±18° (95% confidence limits), which is not far from the vector mean of 062° ±15° (vector strength 23%). Novaya Zemlya has extra glaciers facing northeast and southeast, giving a significant eastward component. This is explained by the effects of wind from westerly directions, mainly through drifting snow to lee slopes.

In Svalbard, 241 out of the 406 glaciers inventoried and classified are 'local'. Mid-altitude is predicted to be minimal at an azimuth of 109° ±46°, an eastward tendency that is significant only when position is included in the regression. However, the vector mean is 014° ±17° with a strength of 21%, so the two approaches are inconsistent. This may relate to the unusually low average gradient (5.8°) and great length (average 8.86 km) of these glaciers, differing by a factor of at least two from those of all other regions, and reducing the importance of aspect. The 'non-local' glaciers have no significant resultant vector, and their lowest altitude is weakly eastward.

Franz Josef Land (81°N) has 995 glaciers, but most of them are ice caps and outlet glaciers and thus not suitable for these analyses. There are 153 glacierets and 6 other local glaciers, yet all but 7 lack either lowest or (mainly) highest altitude in the Inventory. Likewise in Severnaya Zemlya (79°N), highest altitude is normally missing. However, vector analyses of local glaciers show highly significant asymmetry, tending to 312° ±17° for Franz Josef Land and 022° ±24° for the 118 on Severnaya Zemlya, with vector strengths of 33 and 31% respectively.

Further east, all 101 glaciers on Wrangel I. (71°N) are local, and from 0.1 to 1.2 km long. Their vector mean is 335° ±13° but they are lowest when facing

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Table 1. Arctic glaciers in the late twentieth century

Region	Area [km^2]	Number	ELA [m]	Lat. [deg]	Long. [deg]
Alaska					
Brooks Ra.	722	995	1500–2100	69	146W
Canada					
Axel Heiberg I.	11735	1101	200–1200	80	92W
Ellesmere I	80500		200–1000	79	80W
Devon I.	16200	1835	400 ?	75	83W
Bylot I.	5000		500–850	73	78W
Baffin I.	37000		>11,364 300–1100	71	72W
other islands	1356		(150)	77	100W
GREENLAND	76200* excl. ice sheet		0–1600	73	42W
JAN MAYEN I.	115	>30	1000	71	8W
N. NORWAY & SWEDEN	1441*	1487	600–1600	68	17E
SVALBARD	36591	2128	100–800	79	19E
Russia					
Franz Josef Land	13734	988	100–400	81	57E
Novaya Zemlya	23600	685	300–700	76	61E
Ushakov I.	325	2	130	81	80E
Polar Urals	29*	143	600–1000	66	64E
Severnaya Zemlya	18300	287	350–600	79	98E
Byrranga Mts. (Taimyr)	30	96	700–1000	76	108E
Putorana Plateau	2	22	950	69	94E
Orulgan Mts.	18	74	1600–2000	68	128E
Chersk Mts.	155*	372	1900–2300	65	145E
De Longa I.	81	15	200	77	152E
Wrangel I.	3	101	400	71	179E

Mainly from World Glacier Monitoring Service (Haeberli et al. 1989, 1998), updated from Dowdeswell, Hambrey (2002). Note that numbers differ from those cited in the text, based on on-line World Glacier Inventory data
* includes some glaciers south of Arctic Circle

southeast: 143° ±34°. Disregarding position, the 25 north-facing glaciers average 511 m in mid-altitude; the 9 facing south, SE or SW average 292 m. Although small, the numbers are sufficient to provide significant Fourier coefficients and it must be admitted that on Wrangel, as in Svalbard, glacier numbers and altitude reflect aspect in different ways. Thus, in most of the Eurasian Arctic, more local glaciers face northward, but they are often higher than south-facing ones. Linear trends with position seem insufficient here to allow for the regional effects of moisture brought from southerly sources.

In Canada, Axel Heiberg was the subject of a major trial of the Inventory methodology, and Ommanney (1969) provided an early complete Inventory. Although local glaciers have an insignificant vector resultant, the lowest altitude is clearly northward. On the other hand nearby southeast Ellesmere Island, with only 80 local glaciers, has a significant southward resultant but no significant altitude variation.

Further investigation is under way of the effects of glacier type (Table 3) and other characteristics on these results. Anomalies in Svalbard and elsewhere may be due to tidewater glaciers. Calving gives a ‘premature’ glacier termination, such that averaging lowest and highest glacier altitudes does not give a good estimate of ELA – unlike the situation for

Table 2. Vector and regression results and average characteristics for ten Arctic regions, ordered by latitude

Region	number of glaciers	midalt [m]	length [m]	grad [°]	vmean [°]	mindir [°]	vs [%]	asymalt [m]	Lat [°]	Long [°]	abbrev
Suntar-Khayata& Chersk	381	2274	1440	24.8	4	351	78	86	64.4N	142.1E	SK
West Greenland > 64.8N	1775	939	1038	14.8	349	354	38	90	67.9N	52.7W	Gn
Northern Scandinavia	1146	1167	902	20.7	53	35	52	30	68.0N	17.5E	NS
Orulgan	74	1867	724	23.3	25	17	78	44	68.4N	128.5E	Og
Brooks Range	876	1790	1383	20.1	358	25	64	45	68.5N	148.8W	Br
Wrangel I.	101	428	162	18.8	335	144	55	102	71.1N	179.0E	WI
Novaya Zemlya	574	524	3514	11.2	62	98	23	43	74.0N	56.2E	No
SE Ellesmere I.	80	526	4379	15.1	185	323	23	20	77.3N	78.5W	El
Svalbard	241	470	8861	5.8	14	109	21	33	78.5N	15.1E	Sv
Axel Heiberg	289	844	4305	12.9	255	15	7	30	79.3N	91.5E	AH

The variables are: region – region name, number of glaciers – number of glaciers in the analyses, midalt – means of mid-altitude, length – length, grad – gradient, vmean – vector mean direction, mindir – direction of minimum glacier altitude, vs – vector strength, asymalt – degree of altitude asymmetry, Lat – mean latitude, Long – longitude, abbrev – abbreviation for Figs.

Table 3. World Glacier Inventory classification of glaciers in the Eurasian Arctic

Class	Region					
	Svalbard	Nov.Zem	Franz Josef	Sev.Zem.	*	Total
uncertain	27	1	0	0	0	28
field	3	0	0	0	0	3
cap	20	37	349	68	0	474
outlet	115	67	487	100	0	769
valley	237	395	1	17	0	650
mountain	0	158	5	44	22	229
glacieret	4	27	153	57	0	241
shelf	0	0	0	3	0	3
*	488	0	0	0	0	488
Total	894	685	995	289	22	2885

* = missing data

simple mid-latitude glaciers. Also the different mass balance components on Arctic glaciers (Dowdeswell and Hagen 2004; Etzelmüller and Sollid 1996; Hagen et al. 2003) may change the relationships between ELA and glacier geometry. Currently, glacier mid-altitude is available for many more glaciers than is ELA. In the Arctic, the effects of solar radiation on glacier mass balance are present, but are small and easily masked or overturned by other factors such as wind, and varying diurnal cycles of ablation.

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