Climate change information as derived from long-term measurements of winter and summer glacier mass balance

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In nearly all regions of the world, glaciers have shown substantial mass losses over the last decades and are therefore considered as good indicators of global warming. The separate determination of summer and winter balance enables a better understanding of the driving climatological factors, i.e. air temperature as a proxy for the energy balance governing the ablation processes, and solid precipitation as the source of accumulation.

Tab.1: Geographical information for the Alpine and Scandinavian glaciers under discussion. Data source: Fluctuations of Glaciers 1995 - 2000, Vol. VIII, World Glacier Monitoring Service (www.wgms.ch).

Glacier	Country	Latitude	Longitude	H_{max}	H_{min}	Area
		degrees N	degrees E	m a.s.l.	m a.s.l.	km²
Storglaciären	Sweden	67.90	18.57	1720	1140	3.10
Ålfotbreen	Norway	61.75	5.65	1380	1230	4.36
Sarennes	France	45.12	6.17	3190	2830	0.50
Hintereisferner	Austria	46.80	10.77	3727	3011	8.53
Fontana Bianca	Italy	46.48	10.77	3360	2880	0.63
Vernagtferner	Austria	46.88	10.82	3627	2765	8.71
Wurtenkees	Austria	47.03	13.00	3120	2680	0.97

Tab.3: Winter mass balance <bw> and climatological precipitation N for the period 1961 to 1990 (# data starting in 1964). Data source for N: DWD/GPCC, 2007.

Glacier	$\langle b_w \rangle$	Σ N Sept - May
	mm	mm
Storglaciären	1425	375-600
Ålfotbreen	3680#	1800 – 2550
Sarennes	1670	675 - 900
Hintereisferner	970	375 - 600
Vernagtferner	970#	375 - 600

Fig. 1: Location of the studied glaciers, superposed to the climatological precipitation distribution in autumn.

In this study, long term mass balance data of seven mountain glaciers are statistically analysed to show whether a decrease in winter accumulation or an increase in summer melt leads to the observed glacier reductions. The glaciers considered are situated in Norway, Sweden, France, Austria, and Italy (Fig.1). They cover altitudinal ranges from 1140 m a.s.l. to 1720 m a.s.l. (Storglaciären, Sweden) and 3010 m a.s.l. to 3720 m a.s.l. (Hintereisferner, Austria), respectively, with areas between 0.5 km² (Glacier de Sarennes, France) and 8.7 km² (Vernagtferner, Austria) (Tab.1). For all these glaciers, mass gains during winter and mass losses during summer are analysed separately, based on the spatial distribution of snow height and density measurements at the end of April and on the length of the ablation stakes above ice at the end of September. For Ålfotbreen, Glacier de Sarennes and Vernagtferner, Fig. 2 displays the complete time series and the trends of the components.

The main results of the investigations are given in Tab. 2 and can be summarized as follows:

* For all but one glacier (Ålfotbreen), average net mass losses are observed for the periods with direct glaciological mass balance determination.

* For the other glaciers, winter mass balance data show smaller standard deviations than summer mass balances, thus indicating that weather conditions have changed more during summer than in winter.

* The absolute amounts of mass gains in winter are higher for the coastal Ålfotbreen than for the Storglaciären on the downwind side of the mountain range, and there is more winter snowfall on the western Glacier de Sarennes than on all other Alpine glaciers considered here.

* The correlation coefficients R^2 between net mass balance on the one hand, and winter and summer mass balances, on the other, confirm the dominance of weather conditions during summer on the development of mass balance, even for the Norwegian glacier.

Tab. 2: Correlation coefficients R^2, averages and standard deviations of annual <bn>, n, winter <bw>, w, and summer <bs>, s mass balance values, given in mm w.e., for five alpine and two Scandinavian glaciers. Data sources: * : Kuhn et al., 1999; #: Dyurgerov, 2002; ^ : pers. Comm. World Glacier Monitoring Service (www.wgms.ch); $: Munari et al.. 2006.

Glacier	$\langle b_n \rangle$	$\langle b_w \rangle$	$\langle b_s \rangle$	σ_n	σ_w	σ_s	R^2 $\langle b_n \rangle \langle b_w \rangle$	R^2 $\langle b_n \rangle \langle b_s \rangle$	Period of observation
	mm	mm	mm	mm	mm	mm			
Storglaciären #	- 246	1452	- 1698	730	423	508	0.78	0.79	1945/46-1996/97
Ålfotbreen #,^	461	3861	- 3416	1357	1084	660	0.86	0.57	1964/65-1999/00
Sarennes #,^	- 787	1669	- 2375	1047	542	850	0.49	0.83	1948/49-2002/03
Hintereisferner*	- 416	909	- 1325	534	334	534	0.32	0.80	1952/53-1996/97
Fontana Bianca $	- 940	976	- 1916	757	407	753	0.28	0.86	1991/92-2004/05
Vernagtferner	- 330	950	- 1280	501	218	506	0.19	0.91	1964/65-2005/06
Wurtenkees ^	- 790	1370	- 2170	475	300	530	0.11	0.83	1982/83-2000/01

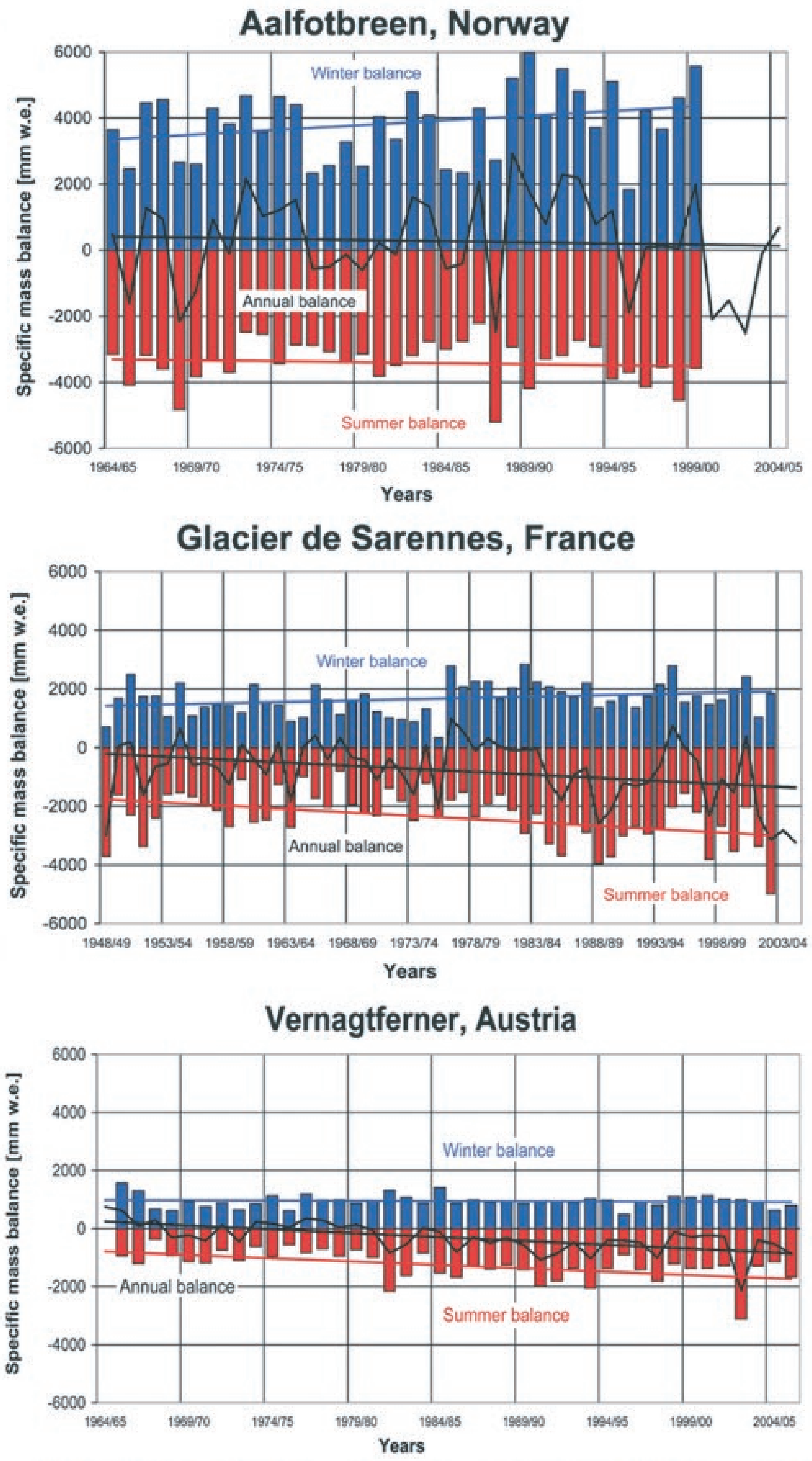

Fig. 2: Time series of mass balance data for winter, summer and for the glaciological year (1 Oct. - 30 Sep.) for three selected glaciers.

Winter mass balance data are compared with average winter precipitation values (standard period 1961 to 1990, Tab. 3) for five glaciers. The precipitation data are valid for an area of 0.5 x 0.5 degrees and are not corrected for altitudinal effects, which most likely explains the difference between <bw> and N. The relative magnitude, however, is depicted correctly with highest amounts in both parameters for the Ålfotbreen and lowest ones for the Hintereisferner and Vernagtferner.

Conclusion

The net mass losses of all the glaciers, discussed here have increased over the last decades, and only the Norwegian one overcompensated the summer losses by increases in winter mass balances! So, global warming and ensuing changes of precipitation clearly influence all the glaciers, most of them only in summer, but some even in winter.

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Photos (KfG Archive): Application of the direct glaciological mass balance determination method.