is emerging that Arctic warming is driving synchronous pan-Arctic responses in the terrestrial and marine cryosphere; reductions in May and June SCE (–7.3% and –19.8% decade^{-1}, respectively) bracket the rate of September sea ice loss (–13.3% decade^{-1}) over the 1979–2014 period for which satellite-derived sea ice extent is available (see section 5i).

As discussed in the *Arctic Report Card: Update for 2014* (http://arctic.noaa.gov/reportcard/snow_cover.html), snow cover duration (SCD) departures derived from the NOAA daily Interactive Multisensor Snow and Ice Mapping System (IMS) snow cover product (Helfrich et al. 2007) show snow cover onset 10–20 days earlier than average (with respect to 1998–2010) across northwestern Russia, northern Scandinavia, the Canadian Arctic Archipelago, and the North Slope of Alaska, with later snow onset over northern Europe and the Mackenzie River region in northwestern Canada (Fig. 5.9b). The spring SCD departures (Fig. 5.9c) are consistent with the April snow depth anomaly pattern [(Fig. 5.9d; derived from the Canadian Meteorological Centre (CMC) daily gridded global snow depth analysis described in Brasnett 1999)] with below-normal snowpack and 20–30 day earlier melt over northern Europe, Siberia, and the central Canadian Arctic. Above-normal snow depths were observed during early spring over much of northern Russia but did not translate into later-than-normal spring snow cover due to above-normal spring temperatures that contributed to rapid ablation (Fig. 5.9d,e). This finding is consistent with the observation of Bulygina et al. (2010) of a trend toward increased winter snow accumulation and a shorter, more intense spring melt period over large regions of Russia.

e. *Glaciers and ice caps outside Greenland*—M. Sharp, G. Wolken, D. Burgess, J. G. Cogley, L. Copland, L. Thomson, A. Arendt, B. Wouters, J. Kohler, L. M. Andreassen, S. O'Neel, and M. Pelto

Mountain glaciers and ice caps cover an area of over 400 000 km^2 in the Arctic, and are a major influence on global sea level (Gardner et al. 2011, 2013; Jacob et al. 2012). They gain mass by snow accumulation and lose mass by meltwater runoff. Where they terminate in water (ocean or lake), they also lose mass by iceberg calving. The climatic mass balance (B_{clim}, the difference between annual snow accumulation and annual meltwater runoff) is a widely used index of how glaciers respond to climate variability and change. The total mass balance (ΔM) is defined as the difference between annual snow accumulation and annual mass losses (by iceberg calving plus runoff).

The World Glacier Monitoring Service (WGMS) maintains the B_{clim} records of 27 glaciers. Data for these glaciers are submitted by national correspondents of the WGMS. As B_{clim} measurements for mass balance year 2013/14 are available for only 12 of the 27 glaciers that are monitored across the Arctic (three each in Alaska, Iceland, Norway, and Svalbard), and some of these are still provisional, this report section focuses primarily on the 24 glaciers for which 2012/13 measurements are available (WGMS 2015). Those glaciers are located in Alaska (three), Arctic Canada (four), Iceland (nine), Svalbard (four) and northern Scandinavia (four) (Fig. 5.10; Table 5.1). For these glaciers as a group, the mean B_{clim} in 2012/13 was negative. However, five glaciers had positive balances: Devon Ice Cap, Meighen Ice Cap, and White Glacier in Arctic Canada; Hofsjökull SW in Iceland; and Hansbreen in Svalbard.

For the Arctic as a whole, 2012/13 was the eleventh most negative mass balance year since records began in 1946, and the sixth most negative year since 1989. At least 20 Arctic glaciers have been measured each

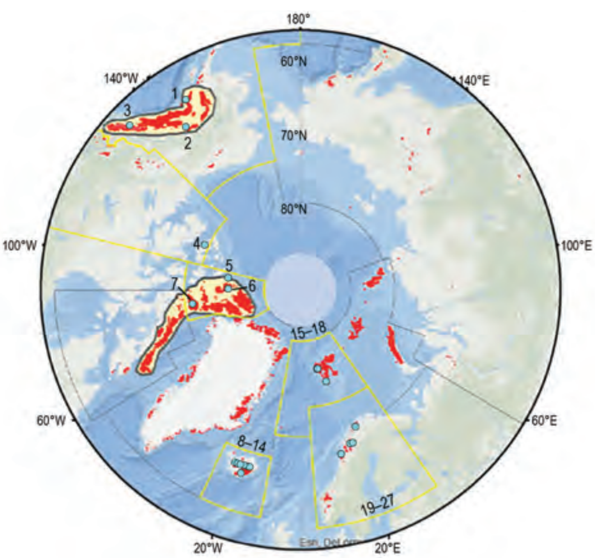

Fig. 5.10. Locations (light blue circles) of 27 Arctic glaciers with long-term records of annual climatic mass balance (B_{clim}). See Table 5.1 for glacier names. Regions outlined in yellow are the Randolph Glacier Inventory (RGI) regions for major regions of the Arctic. In regions where individual glaciers are located too close together to be identifiable on the map, their numbers are shown at the edge of the RGI region in which they occur. Red shading indicates glaciers and ice caps, including ice caps in Greenland outside the ice sheet. Yellow shading shows the solution domains for regional mass balance estimates for the Canadian Arctic and Gulf of Alaska regions derived using gravity data from the GRACE satellites (see Fig. 5.12).

TABLE 5.1. Measured annual climatic mass balance (B_{clim}) of glaciers in Alaska, Arctic Canada, Iceland, Svalbard, and northern Scandinavia for 2012/13 and 2013/14, together with the mean and standard deviation for each glacier for the period 1980–2010. Numbers in column 1 identify glacier locations in Fig. 5.10. Mass balance data are from the World Glacier Monitoring Service, with corrections to Svalbard data provided by J. Kohler and to Alaska data provided by S. O'Neel. The 2013/14 data for Langfjordjøkelen and all data for Rundvassbreen were provided by L. Andreassen. Note that 2013/14 results may be based upon data collected before the end of the 2014 melt season and may be subject to revision.

Region	Glacier (Record length, years)	Mean Climatic Balance 1980–2010 (kg m^{-2} yr^{-1})	Standard Deviation of Climatic Mass balance 1980–2010 (kg m^{-2} yr^{-1})	Climatic Balance 2012–13 (kg m^{-2} yr^{-1})	Climatic Balance 2013–14 (kg m^{-2} yr^{-1})
Alaska					
1	Wolverine (49)	−285	1205	−2250	−1400
3	Lemon Creek (62)	−584	709	−750	−1825
2	Gulkana (49)	−505	738	−1190	−80
Arctic Canada					
7	Devon Ice Cap (53)	−153	176	+24	
5	Meighen Ice Cap (52)	−173	284	+160	
4	Melville South Ice Cap (51)	−295	369	−172	
6	White (51)	−239	260	+45	
Iceland					
8	Langjökull S. Dome (17)	−1448	817	−851	
9	Hofsjökull E (24)	−602	1009	−440	−990
9	Hofsjökull N (25)	−606	787	−360	−950
9	Hofsjökull SW (24)	−978	947	+60	−990
14	Köldukvislarjökull (21)	−529	738	−560	
10	Tungnaarjökull (22)	−1170	873	−810	
13	Dyngjujökull (16)	−133	912	−230	
12	Brúarjökull (21)	−367	660	−70	
11	Eyjabakkajökull (22)	−867	813	−500	
Svalbard					
17	Midre Lovenbreen (47)	−356	305	−940	+50
16	Austre Broggerbreen (48)	−469	342	−1090	+10
15	Kongsvegen (28)	−70	378	−690	+116
18	Hansbreen (25)	−431	512	+143	
Northern Scandinavia					
20	Engabreen (41)	+463	1091	−1779	−890
21	Langfjordjøkelen (24)	−927	781	−2615	−780
22	Marmaglaciaren (23)	−430	525		
23	Rabots Glaciar (29)	−394	560		
24	Riukojietna (26)	−592	805		
25	Storglaciaren (68)	−113	698	−1406	
26	Tarfalaglaciaren (18)	−212	1101		
27	Rundvassbreen (7)	−777		−2430	−790

year since 1989. For the three Canadian glaciers with positive 2012/13 climatic balances, the balances were among the 7–13 most positive since measurements began in 1960. Only nine years since 1960 have had positive measured glacier climatic balance in Arctic Canada; 2012/13 was only the second since 1986.

The 2012/13 positive balances of Arctic Canada glaciers were most likely linked to melt suppression by anomalously cool temperatures over the Canadian Arctic Islands in summer 2013, when June–August mean air temperatures at 850 hPa were 0.5°–2.5°C below the 1981–2010 mean, according to the NCEP-NCAR R1 Reanalysis (Kalnay et al. 1996). By contrast, near-record negative 2012/13 climatic balances in northern Scandinavia coincided with June–August 850-hPa air temperatures 1.0°–2.5°C above the 1981–2010 mean. Strongly negative climatic balances in Alaska and Svalbard were also linked to positive 850-hPa air temperature anomalies in these regions in summer 2013. The positive and negative near-surface air temperature anomalies described here are illustrated in Overland et al. (2013, 2014b).

Among the 12 glaciers for which the 2013/14 climatic balances have been reported (Table 5.1), Svalbard glacier balances were all positive, while those in Alaska, Norway, and Iceland were all negative. Local observations suggest that the positive balances in Svalbard were attributable to high winter precipitation, especially at low elevations, followed by a relatively cool summer. On the other hand, Alaska, northern Scandinavia, and Iceland all had positive 850-hPa air temperature anomalies in July–September 2014, exceeding +2.5°C in parts of northern Norway and Sweden, according to NCEP/NCAR R1 (Overland et al. 2014b). In Norway, 2014 was the warmest year on record (2.2°C above the 1961–90 mean) and temperatures in July were 4.3°C above the long-term mean.

Cumulative regional climatic mass balances, derived by summing the annual mean climatic mass balances for all glaciers in each reporting region of the Arctic, have become increasingly negative over the past two decades (Fig. 5.11). These negative trends are also evident in regional total mass balance estimates (ΔM) for the heavily glaciated regions of Arctic Canada and Alaska derived using GRACE satellite gravimetry (Fig. 5.12). Measurements of ΔM for all the glaciers and ice caps in Arctic Canada clearly show a negative mass balance year in that region in 2013/14, as do measurements for Alaska. Since summer air temperatures over Arctic Canada were not unusually warm in 2014, the negative mass balance there may be linked to the relatively low snow accumulation in winter 2013/14 that is apparent in the GRACE data. In Alaska, however, anomalously warm (up to +1.0°C) summer temperatures in 2014 were likely a factor in that region's negative balance.

f. Greenland Ice Sheet—M. Tedesco, J. E. Box, J. Cappelen, X. Fettweis, T. Mote, R. S. W. van de Wal, M. van den Broeke, C. J. P. P. Smeets, and J. Wahr

Melt extent for the period June–August (JJA, "summer" or melt season) 2014, estimated from microwave brightness temperatures measured by the Special Sensor Microwave Imager/Sounder (SSMI/S; e.g., Mote 2007; Tedesco et al. 2013a,b), was above the 1981–2010 average 90% of the time (83 of 92 days; Fig. 5.13a), with positive anomalies reaching maximum values along the western ice sheet.

The number of days of surface melting in June and July 2014 exceeded the 1981–2010 average over most of the ice sheet, particularly along the southwestern margin (Fig. 5.13b), the latter consistent with the anomalously high temperatures recorded at coastal stations in western Greenland during that period (Tedesco et al. 2014). The number of days of surface melting was also particularly high on the northeastern margin of the ice sheet

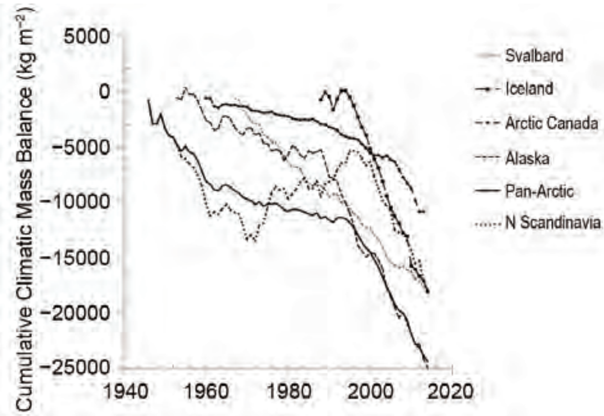

FIG. 5.11. Cumulative climatic mass balances (B_{clim} in kg m^{-2}) for glaciers in five regions of the Arctic, and for the Arctic as a whole (Pan-Arctic). Mean balances are calculated for glaciers monitored in each region in each year and these means are cumulated over the period of record. Note that the period of monitoring varies between regions and that the number and identity of glaciers monitored in a given region may vary between years.

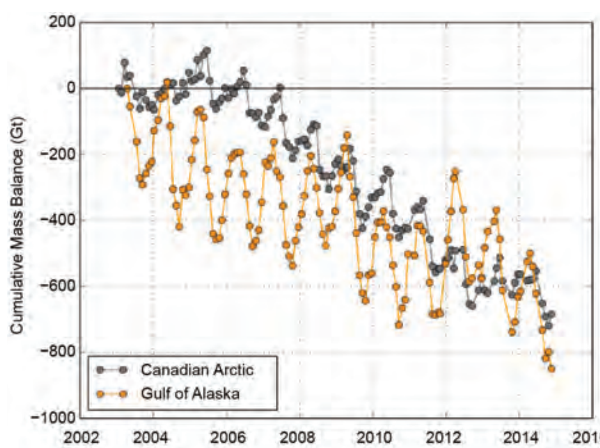

FIG. 5.12. Cumulative total mass balance (ΔM in gigatonnes, Gt) of glaciers in the Canadian Arctic and the Gulf of Alaska region for 2003–15. The uncertainty of the calculated mass balances is ±8 Gt yr^{-1} for the Gulf of Alaska and ±9 Gt yr^{-1} for the Canadian Arctic. This includes the formal error of the least squares fit and the uncertainties in the corrections for glacial isostatic adjustment, Little Ice Age, and hydrology.