Climate Change 2013: The Physical Science Basis

Working Group I contribution to the IPCC Fifth Assessment Report

Chapter 4 – Observations of the Cryosphere

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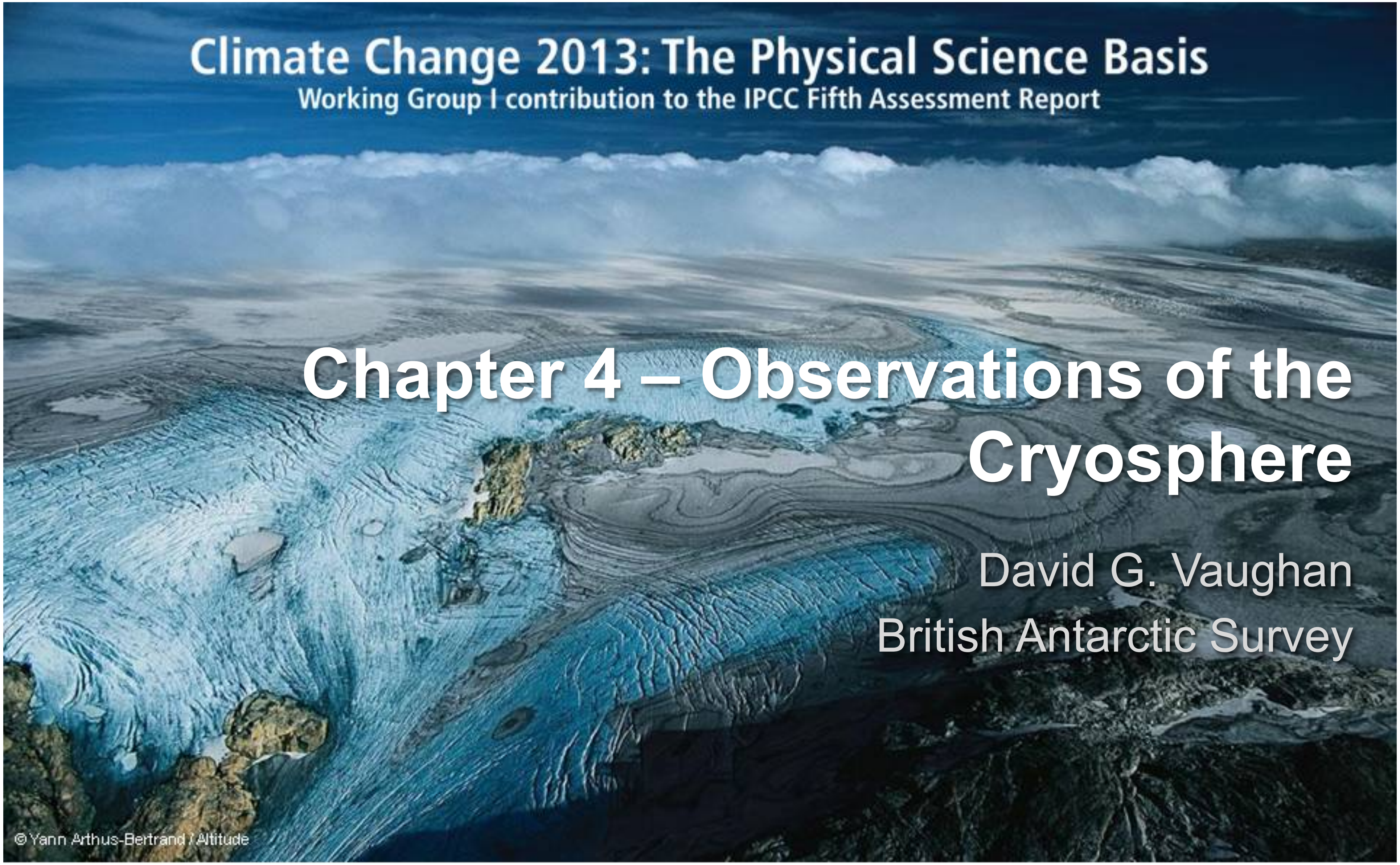

INTERGOVERNMENTAL PANEL ON climate change

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Framing

- Ownership and design
- Timescales
- Review process
- Governmental influence?
- “Consensus”

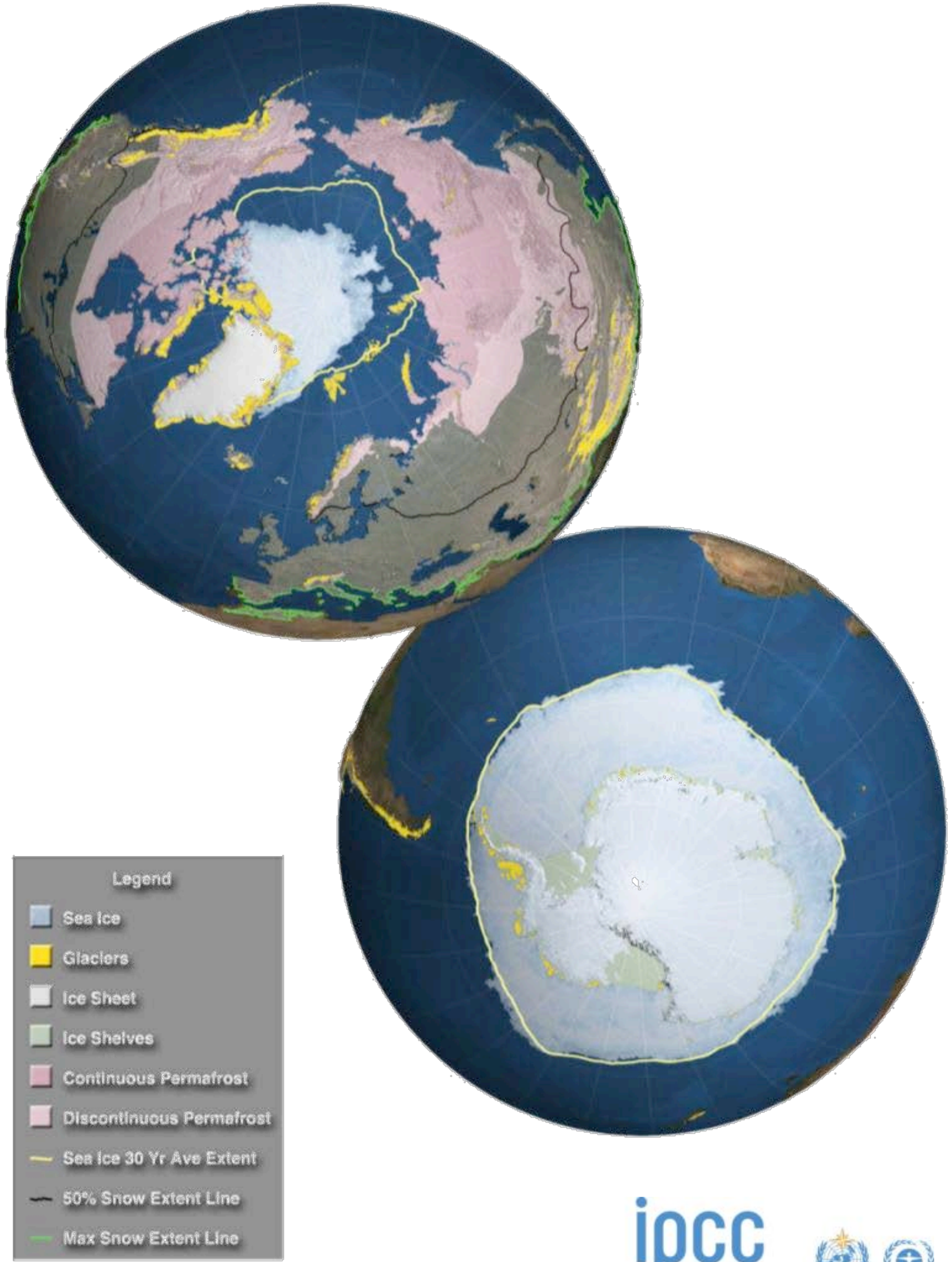
Structure

- Summary for policymakers
- Technical summary
- Chapters 2
- Appendices
- Supplementary material

The Cryosphere

"The cryosphere, comprising snow, river and lake ice, sea ice, glaciers, ice shelves and ice sheets, and frozen ground...

... plays a major role in the Earth's climate system through its impact on the surface energy budget, the water cycle, primary productivity, surface gas exchange and sea level."



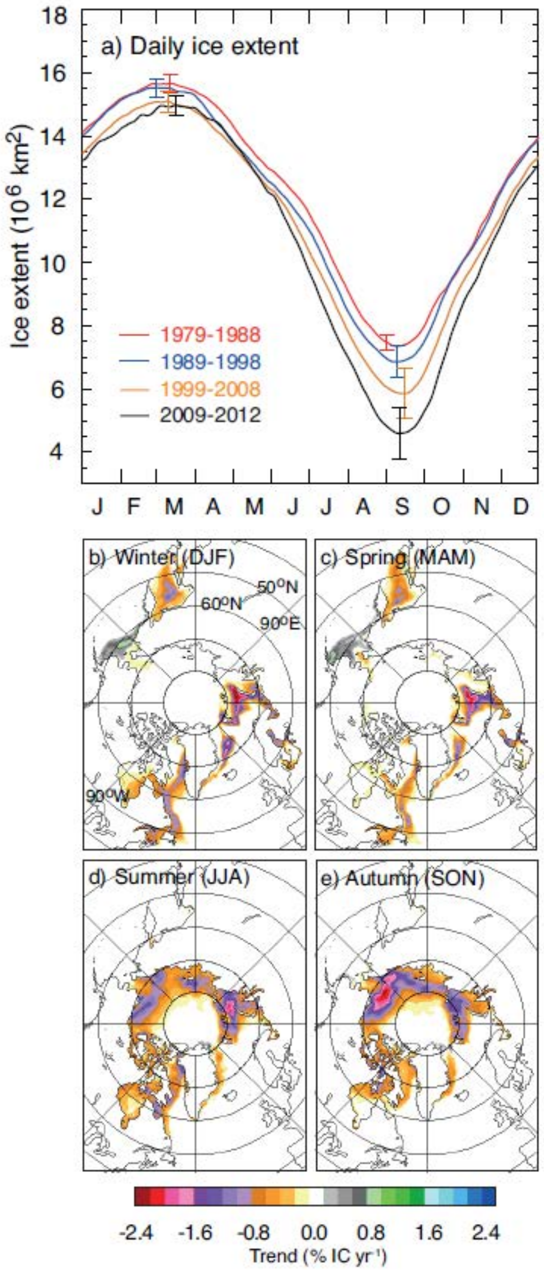
The Cryosphere

"The Cryosphere is often referred to as a 'natural thermometer'. But as our understanding of the complexity of this response has grown, it is increasingly clear that elements of the cryosphere should rather be considered as a 'natural climate-meter', responsive not only to temperature but also to other climate variables (e.g., precipitation)."

"However, it remains the case that the conspicuous and widespread nature of changes in the cryosphere (in particular, sea ice, glaciers and ice sheets) means these changes are frequently used emblems of the impact of changing climate. It is thus imperative that we understand the context of current change within the framework of past changes and natural variability."

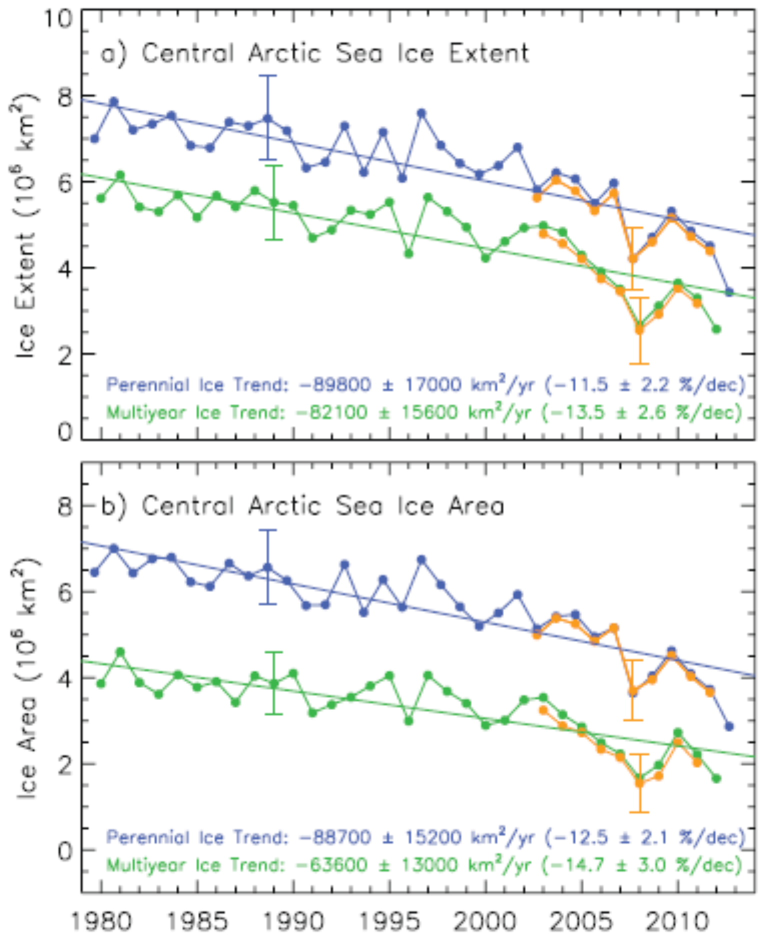
Sea ice

Continuing the trends reported in AR4, the annual Arctic sea ice extent decreased over the period 1979–2012. The rate of this decrease was very likely[1] between 3.5 and 4.1% per decade (0.45 to 0.51 million km[2] per decade). The average decrease in decadal extent of Arctic sea ice has been most rapid in summer and autumn (high confidence[2]), but the extent has decreased in every season, and in every successive decade since 1979 (high confidence). {4.2.2, Figure 4.2}



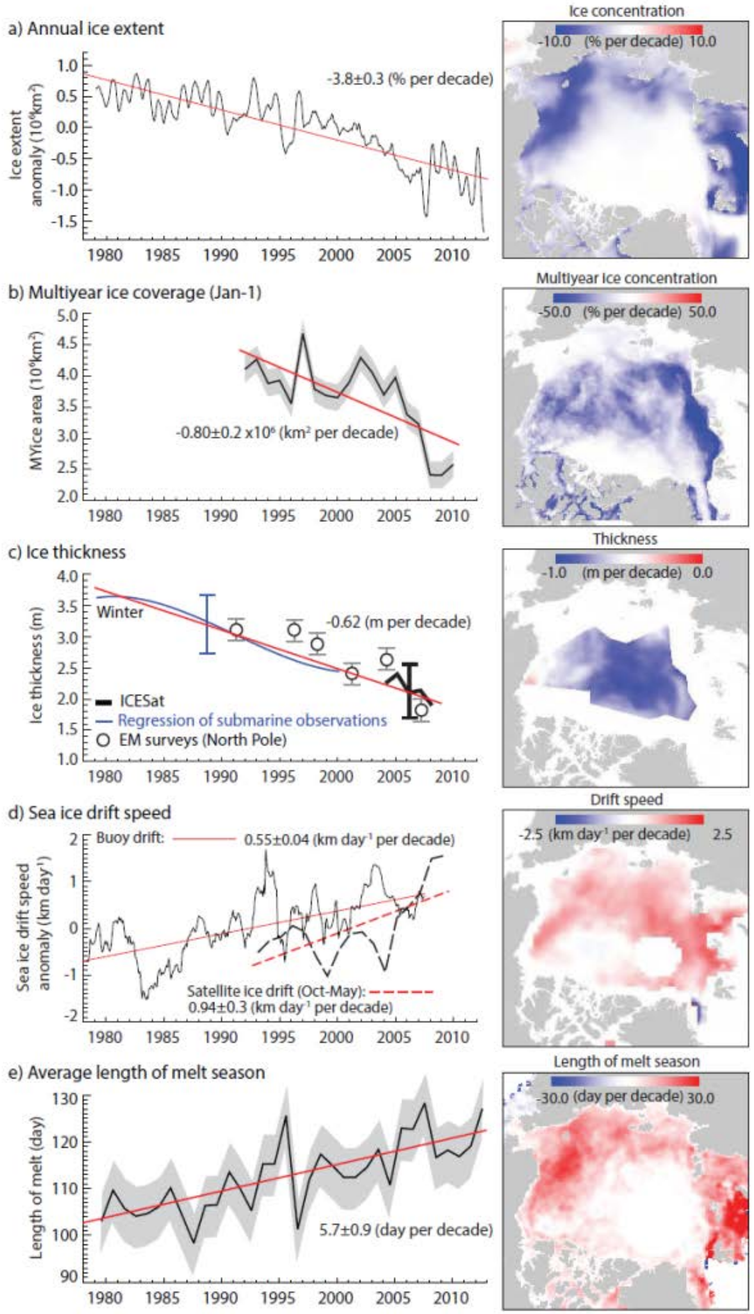
Sea ice

The extent of Arctic perennial and multi-year sea ice decreased between 1979 and 2012 (very high confidence). The perennial sea ice extent (summer minimum) decreased between 1979 and 2012 at 11.5 ± 2.1% per decade (0.73 to 1.07 million km_2 per decade) (very likely) and the multi-year ice (that has survived two or more summers) decreased at a rate of 13.5 ± 2.5% per decade (0.66 to 0.98 million km_2 per decade) (very likely). {4.2.2, Figures 4.4, 4.6}

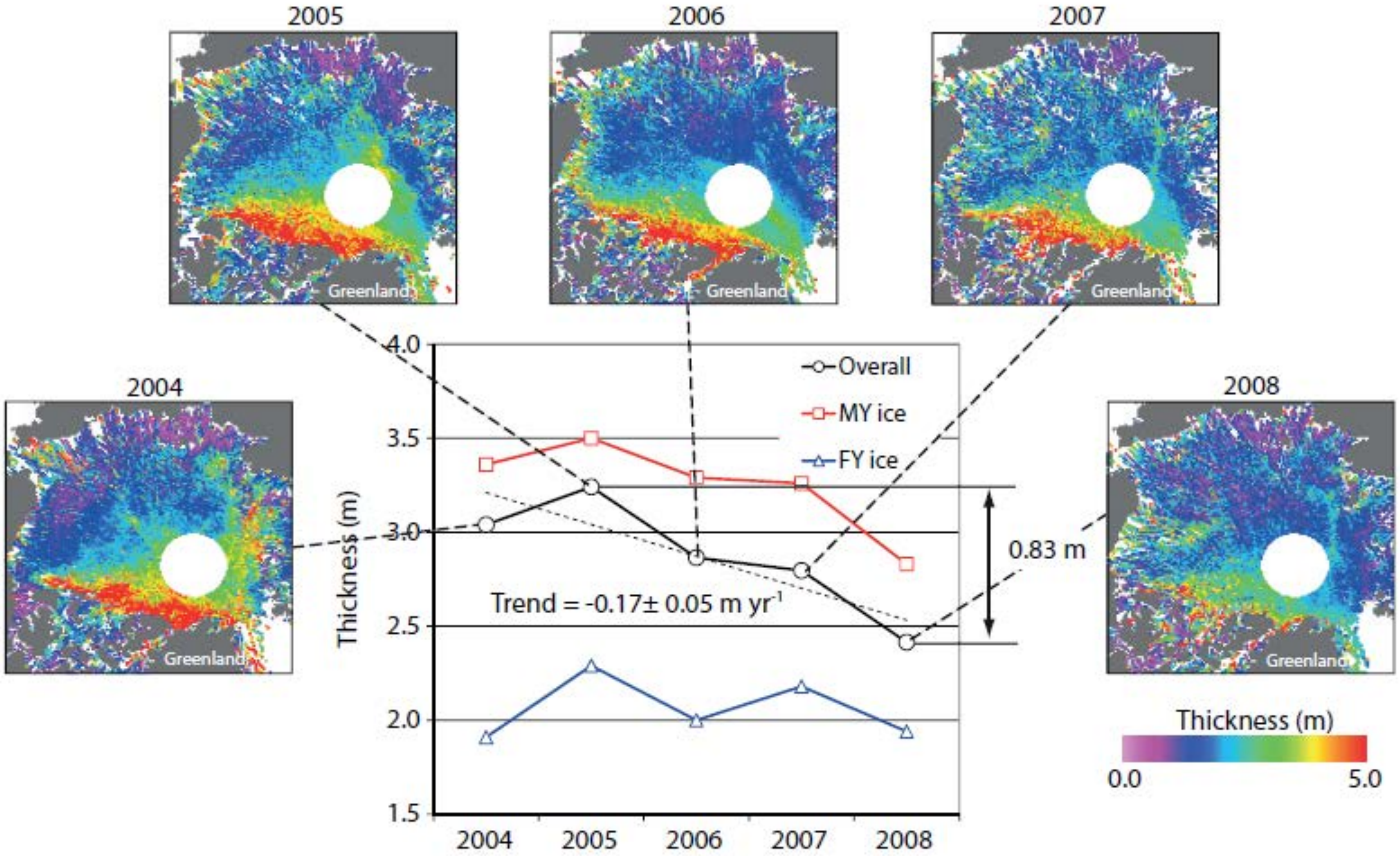


Sea ice

The average winter sea ice thickness within the Arctic Basin decreased between 1980 and 2008 (high confidence). The average decrease was likely between 1.3 and 2.3 m. High confidence in this assessment is based on observations from multiple sources: submarine, electro-magnetic (EM) probes, and satellite altimetry, and is consistent with the decline in multi-year and perennial ice extent {4.2.2, Figures 4.5, 4.6}
Satellite measurements made in the period 2010–2012 show a decrease in sea ice volume compared to those made over the period 2003–2008 (medium confidence). There is high confidence that in the Arctic, where the sea ice thickness has decreased, the sea ice drift speed has increased. {4.2.2, Figure 4.6}



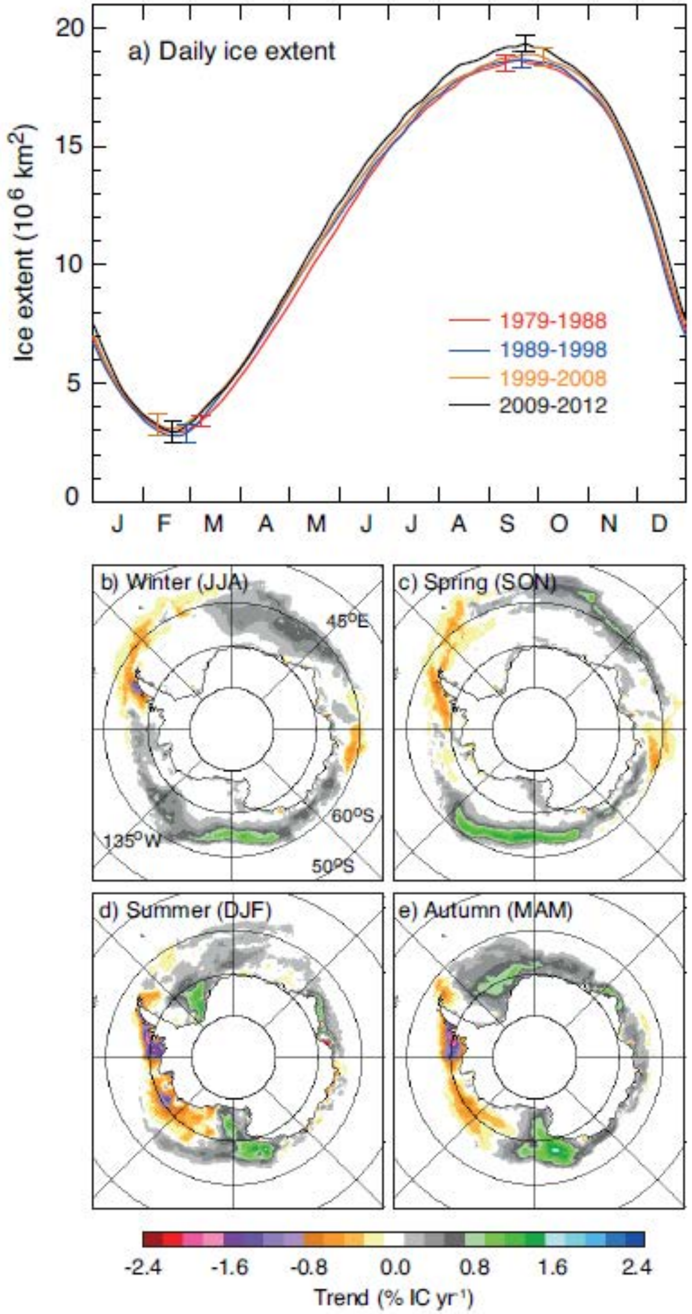
Sea ice



2005
2006
2007
2004
2008
Greenland
Overall
MY ice
FY ice
Thickness (m)
Trend = -0.17± 0.05 m yr⁻¹
0.83 m
4.0
3.5
3.0
2.5
2.0
1.5
2004
2005
2006
2007
2008
Thickness (m)
0.0
5.0

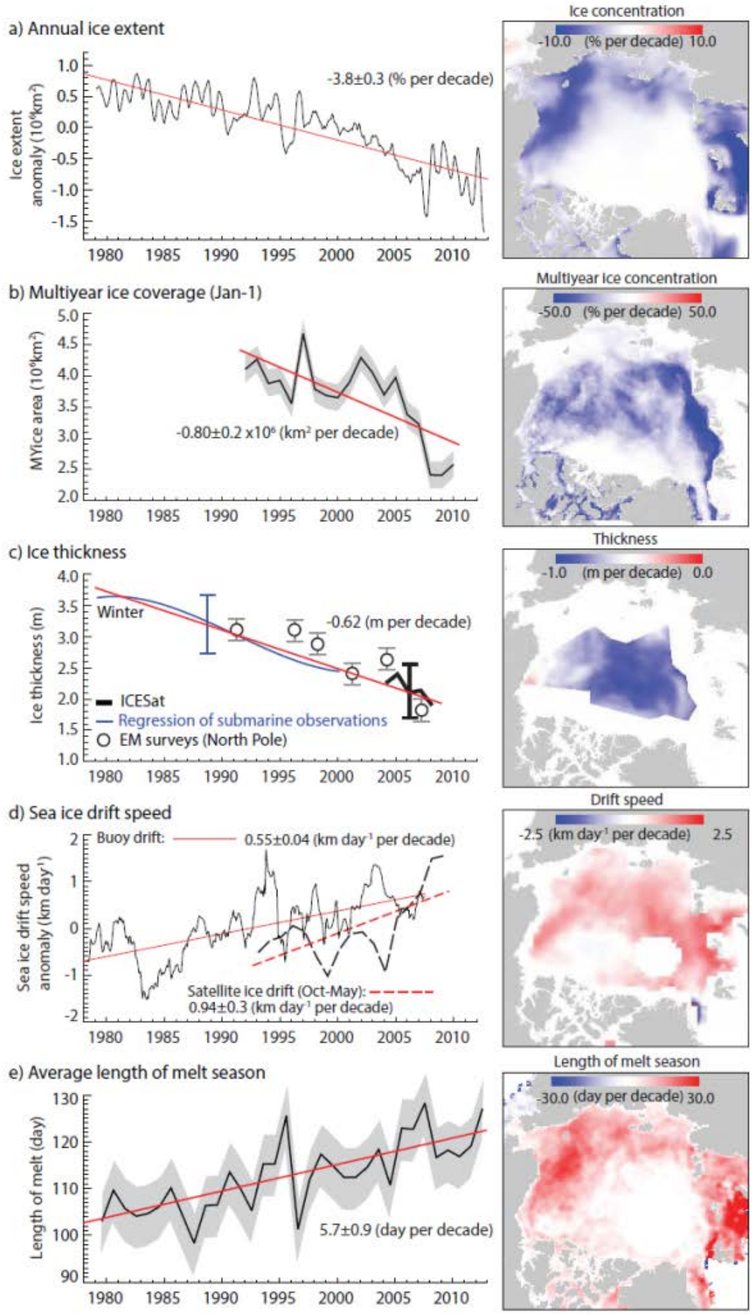
Sea ice (2)

It is very likely that the annual Antarctic sea ice extent increased at a rate of between 1.2 and 1.8% per decade (0.13 to 0.20 million km2 per decade) between 1979 and 2012. There was a greater increase in sea ice area, due to a decrease in the percentage of open water within the ice pack. There is high confidence that there are strong regional differences in this annual rate, with some regions increasing in extent/area and some decreasing {4.2.3, Figure 4.7}



Sea ice (2)

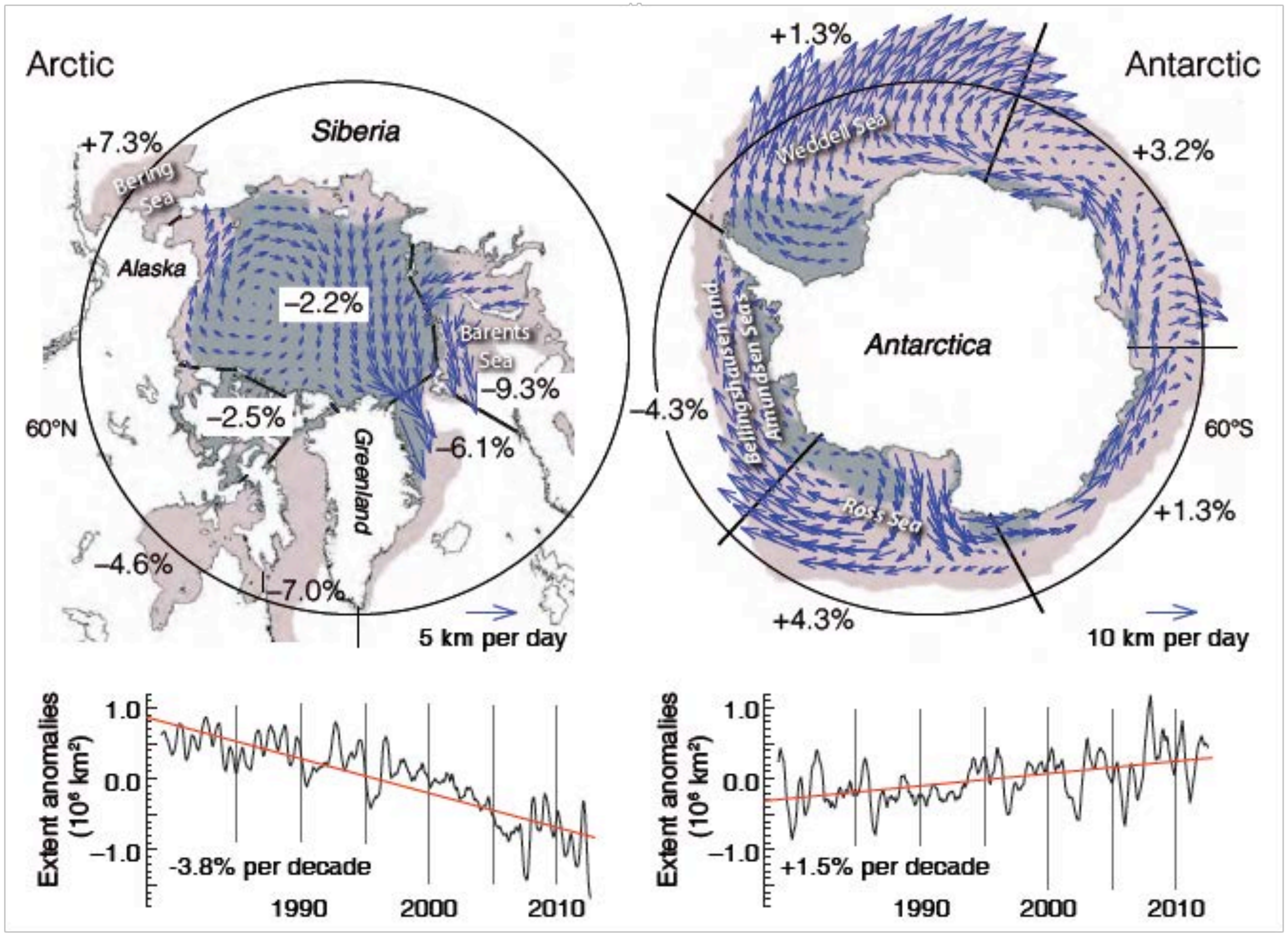
It is likely that the annual period of surface melt on Arctic perennial sea ice lengthened by 5.7 ± 0.9 days per decade over the period 1979–2012. Over this period, in the region between the East Siberian Sea and the western Beaufort Sea, the duration of ice-free conditions increased by nearly 3 months. {4.2.2, Figure 4.6}



Sea ice

Frequently Asked Questions

FAQ 4.1 | How Is Sea Ice Changing in the Arctic and Antarctic?



FAQ 4.1, Figure 1 | The mean circulation pattern of sea ice and the decadal trends (%) in annual anomalies in ice extent (i.e., after removal of the seasonal cycle), in different sectors of the Arctic and Antarctic. Arrows show the average direction and magnitude of ice drift. The average sea ice cover for the period 1979 through 2012, from satellite observations, at maximum (minimum) extent is shown as orange (grey) shading.

Global Glaciers

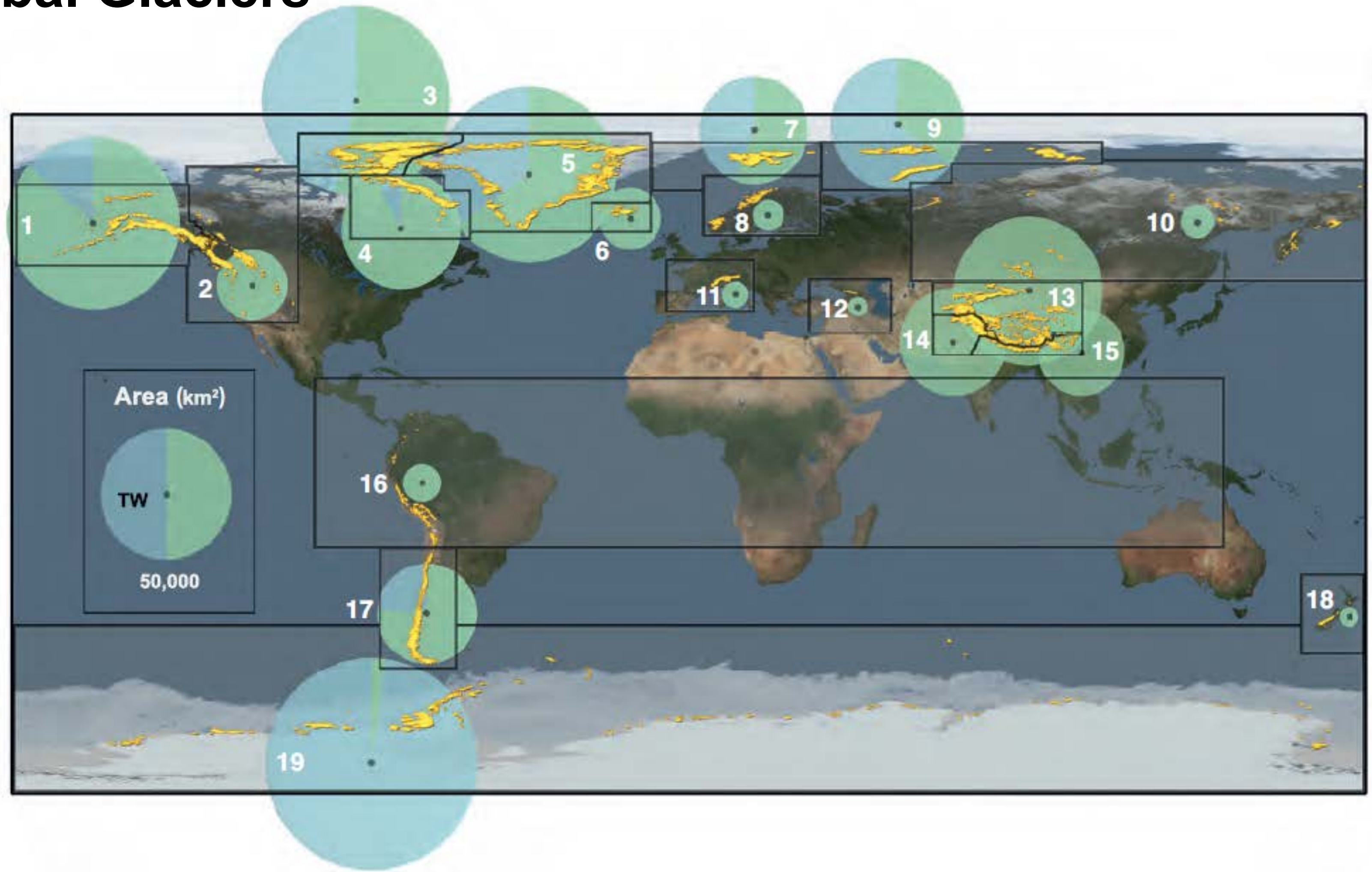


Figure 4.8 | Global distribution of glaciers (yellow, area increased for visibility) and area covered (diameter of the circle), sub-divided into the 19 RGI regions (white number) referenced in Table 4.2. The area percentage covered by tidewater (TW) glaciers in each region is shown in blue. Data from Arendt et al. (2012) and Gardner et al. (2013).

Global Glaciers

Region	Region Name	Number of Glaciers	Area (km²)	Percent of total area	Tidewater fraction (%)	Mass (minimum) (Gt)	Mass (maximum) (Gt)	Mean SLE (mm)
1	Alaska	23,112	89,267	12.3	13.7	16,168	28,021	54.7
2	Western Canada and USA	15,073	14,503.5	2.0	0	906	1148	2.8
3	Arctic Canada North	3318	103,990.2	14.3	46.5	22,366	37,555	84.2
4	Arctic Canada South	7342	40,600.7	5.6	7.3	5510	8845	19.4
5	Greenland	13,880	87,125.9	12.0	34.9	10,005	17,146	38.9
6	Iceland	290	10,988.6	1.5	0	2390	4640	9.8
7	Svalbard	1615	33,672.9	4.6	43.8	4821	8700	19.1
8	Scandinavia	1799	2833.7	0.4	0	182	290	0.6
9	Russian Arctic	331	51,160.5	7.0	64.7	11,016	21,315	41.2
10	North Asia[a]	4403	3425.6	0.4	0	109	247	0.5
11	Central Europe	3920	2058.1	0.3	0	109	125	0.3
12	Caucasus	1339	1125.6	0.2	0	61	72	0.2
13	Central Asia	30,200	64,497	8.9	0	4531	8591	16.7
14	South Asia (West)	22,822	33,862	4.7	0	2900	3444	9.1
15	South Asia (East)	14,006	21,803.2	3.0	0	1196	1623	3.9
16	Low Latitudes[a]	2601	2554.7	0.6	0	109	218	0.5
17	Southern Andes[a]	15,994	29,361.2	4.5	23.8	4241	6018	13.5
18	New Zealand	3012	1160.5	0.2	0	71	109	0.2
19	Antarctic and Sub-Antarctic	3274	13,2267.4	18.2	97.8	27,224	43,772	96.3
	Total	168,331	726,258.3		38.5	113,915	191,879	412.0

Global Glaciers

Glaciers

Since AR4, almost all glaciers worldwide have continued to shrink as revealed by the time series of measured changes in glacier length, area, volume and mass (very high confidence). Measurements of glacier change have increased substantially in number since AR4. Most of the new data sets, along with a globally complete glacier inventory, have been derived from satellite remote sensing. {4.3.1, 4.3.3, Figures 4.9, 4.10, 4.11}

Between 2003 and 2009, most of the ice lost was from glaciers in Alaska, the Canadian Arctic, the periphery of the Greenland ice sheet, the Southern Andes and the Asian Mountains (very high confidence). Together these regions account for more than 80% of the total ice loss. {4.3.3, Figure 4.11, Table 4.4}

Total mass loss from all glaciers in the world, excluding those on the periphery of the ice sheets, was very likely 226 ± 135 Gt yr–1 (sea level equivalent, 0.62 ± 0.37 mm yr–1) in the period 1971–2009, 275 ± 135 Gt yr–1 (0.76 ± 0.37 mm yr–1) in the period 1993–2009, and 301 ± 135 Gt yr–1 (0.83 ± 0.37 mm yr–1) between 2005 and 2009. {4.3.3, Figure 4.12, Table 4.5}

Current glacier extents are out of balance with current climatic conditions, indicating that glaciers will continue to shrink in the future even without further temperature increase (high confidence). {4.3.3}

Global Glaciers

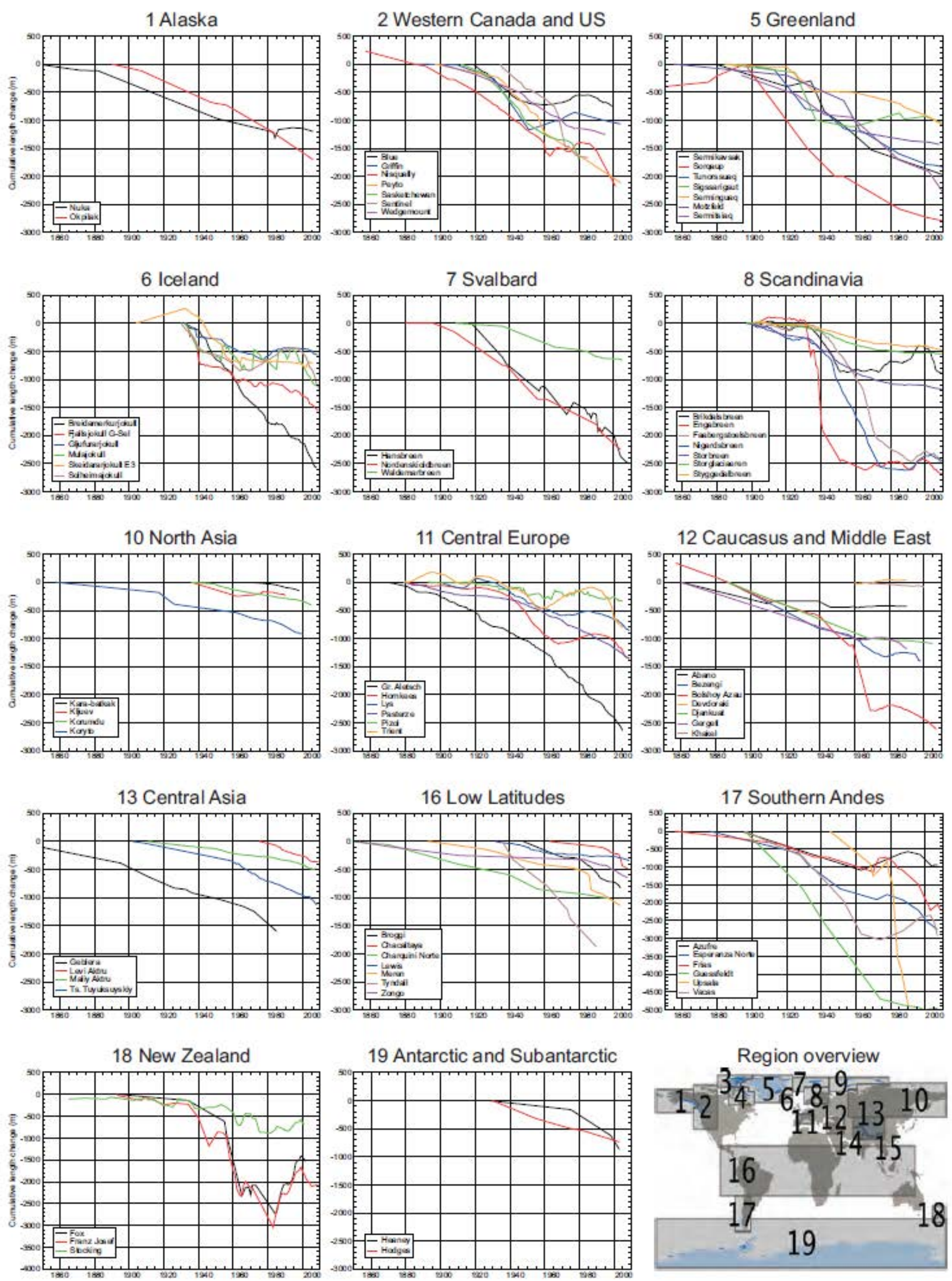
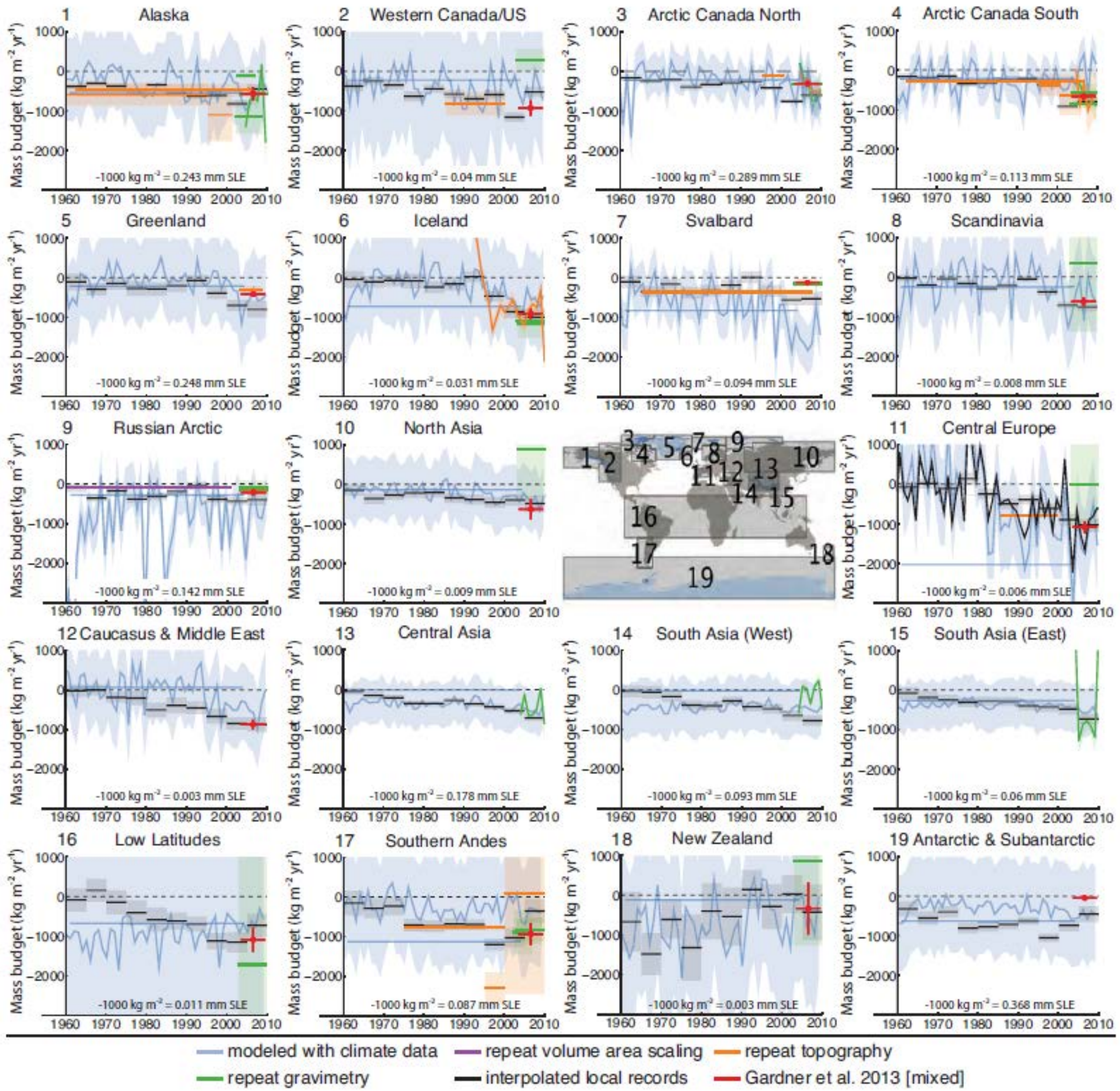


Figure 4.9 | Selection of long-term cumulative glacier length changes as compiled from in situ measurements (WGMS, 2008), reconstructed data points added to measured time series (region 5) from Leclercq et al. (2012), and additional time series from reconstructions (regions 1, 2, 7, 10, 12, 16, 17 and 18) from Leclercq and Oerlemans (2012)…

Global Glaciers

Figure 4.11 | Regional glacier mass budgets in units of kg m–2 yr–1 for the world's 19 glacierized regions (Figure 4.8 and Table 4.2). Estimates are from modelling with climate data (blue), repeat volume area scaling (magenta), interpolation of local glacier records (black), or airborne and/or satellite repeat topographic mapping (orange). …



Global Glaciers

Table 4.4 | Regional mass change rates in units of kg m–2 yr–1 and Gt yr–1 for the period 2003–2009 from Gardner et al. (2013)…

No.	Region Name	($kg\ m^{-2}\ yr^{-1}$)	($Gt\ yr^{-1}$)
1	Alaska	–570 ± 200	–50 ± 17
2	Western Canada and USA	–930 ± 230	–14 ± 3
3	Arctic Canada North	–310 ± 40	–33 ± 4
4	Arctic Canada South	–660 ± 110	–27 ± 4
5	Greenland periphery	–420 ± 70	–38 ± 7
6	Iceland	–910 ± 150	–10 ± 2
7	Svalbard	–130 ± 60	–5 ± 2
8	Scandinavia	–610 ± 140	–2 ± 0
9	Russian Arctic	–210 ± 80	–11 ± 4
10	North Asia	–630 ± 310	–2 ± 1
11	Central Europe	–1060 ± 170	–2 ± 0
12	Caucasus and Middle East	–900 ± 160	–1 ± 0
13–15	High Mountain Asia	–220 ± 100	–26 ± 12
16	Low Latitudes	–1080 ± 360	–4 ± 1
17	Southern Andes	–990 ± 360	–29 ± 10
18	New Zealand	–320 ± 780	0 ± 1
19	Antarctic and Sub-Antarctic	–50 ± 70	–6 ± 10
	Total	**–350 ± 40**	**–259 ± 28**

Global Glaciers

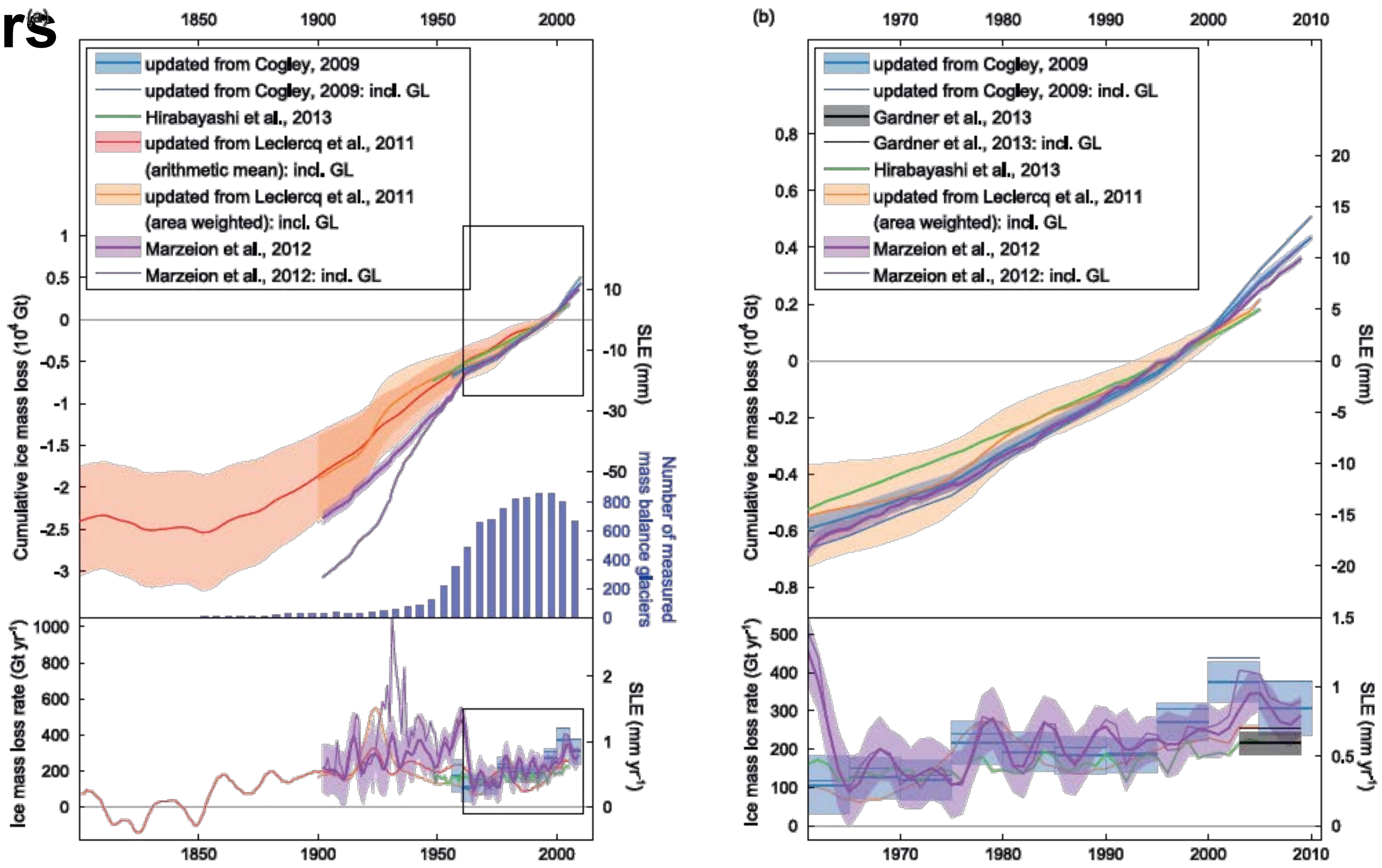


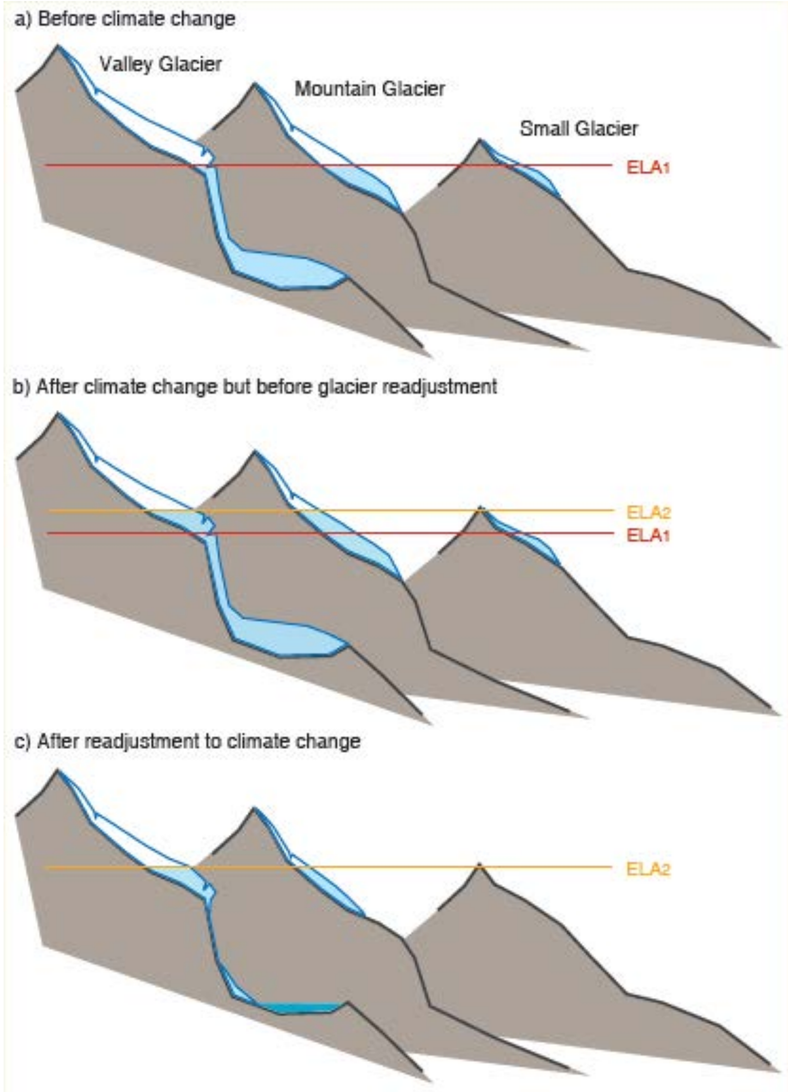
Figure 4.12 | Global cumulative (top graphs) and annual (lower graphs) glacier mass change for (a) 1801–2010 and (b) 1961–2010. The cumulative estimates are all set to zero mean over 1986–2005. Estimates are based on glacier length variations (updated from Leclercq et al., 2011), from area-weighted extrapolations of individual directly and geodetically measured glacier mass budgets (updated from Cogley, 2009b), and from modelling with atmospheric variables as input (Marzeion et al., 2012; Hirabayashi et al., 2013).

Frequently Asked Questions

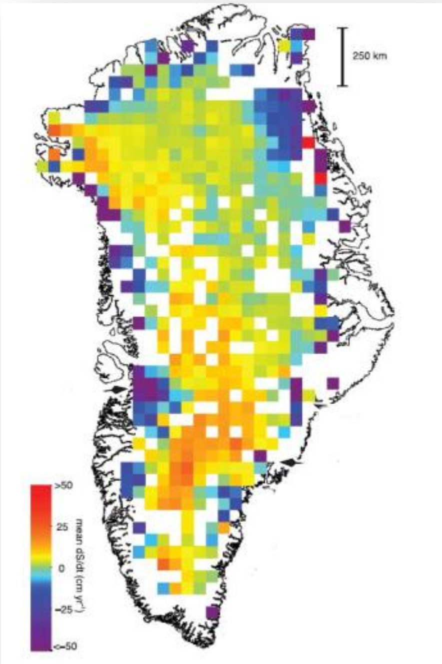
FAQ 4.2 | Are Glaciers in Mountain Regions Disappearing?

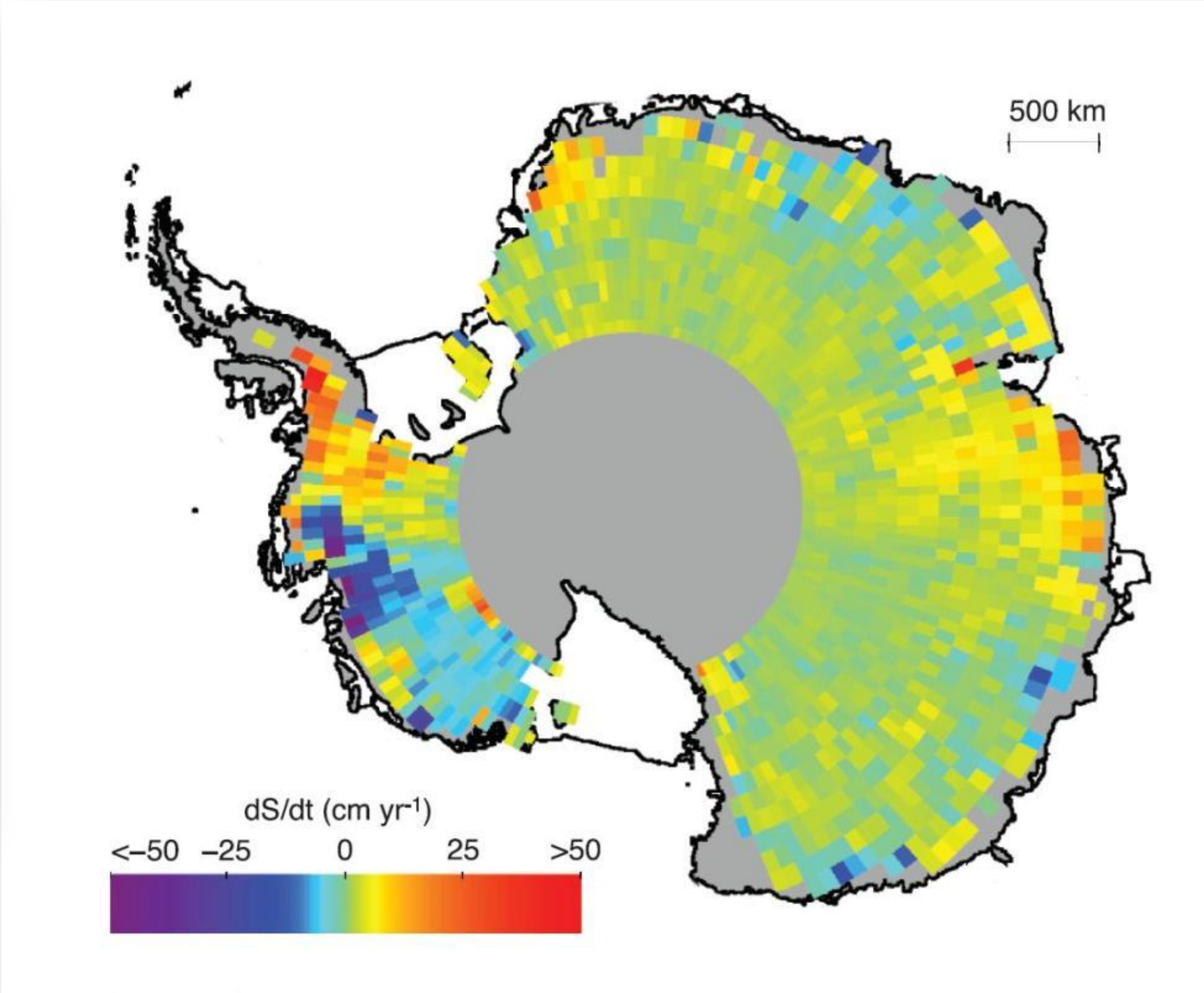
Current glacier extents are out of balance with current climatic conditions, indicating that glaciers will continue to shrink in the future even without further temperature increase (high confidence). {4.3.3}

In many mountain ranges around the world, glaciers are disappearing in response to the atmospheric temperature increases of past decades. Disappearing glaciers have been reported in the Canadian Arctic and Rocky Mountains; the Andes; Patagonia; the European Alps; the Tien Shan; tropical mountains in South America, Africa and Asia and elsewhere. In these regions, more than 600 glaciers have disappeared over the past decades. Even if there is no further warming, many more glaciers will disappear. It is also likely that some mountain ranges will lose most, if not all, of their glaciers.



Ice sheets in AR4





Ice sheets (1)

The Greenland ice sheet has lost ice during the last two decades (very high confidence). Combinations of satellite and airborne remote sensing together with field data indicate with high confidence that the ice loss has occurred in several sectors and that large rates of mass loss have spread to wider regions than reported in AR4. {4.4.2, 4.4.3, Figures 4.13, 4.15, 4.17}

The rate of ice loss from the Greenland ice sheet has accelerated since 1992. The average rate has very likely increased from 34 [–6 to 74] Gt yr–1 over the period 1992–2001 (sea level equivalent, 0.09 [–0.02 to 0.20] mm yr–1), to 215 [157 to 274] Gt yr–1 over the period 2002–2011 (0.59 [0.43 to 0.76] mm yr–1). {4.4.3, Figures 4.15, 4.17}

Ice loss from Greenland is partitioned in approximately similar amounts between surface melt and outlet glacier discharge (medium confidence), and both components have increased (high confidence). The area subject to summer melt has increased over the last two decades (high confidence). {4.4.2}

Ice sheets (2)

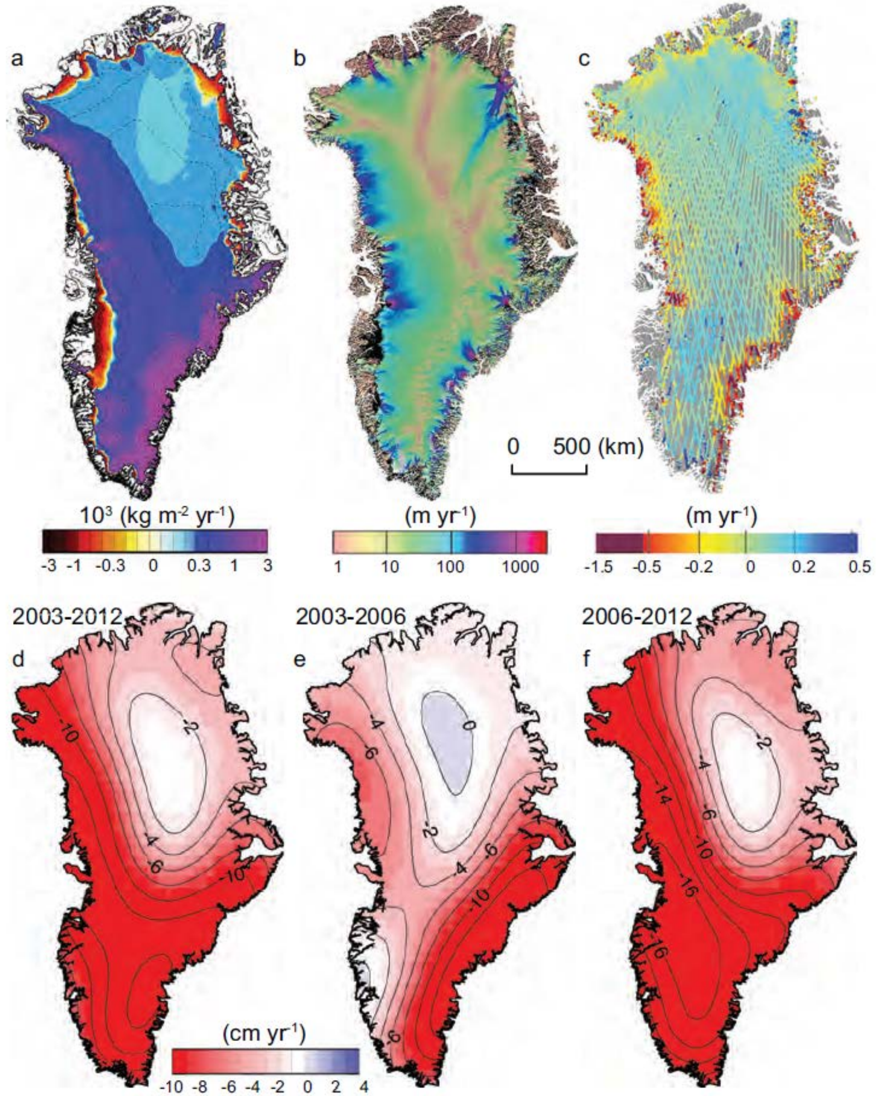
The Antarctic ice sheet has been losing ice during the last two decades (high confidence). There is very high confidence that these losses are mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica, and high confidence that they result from the acceleration of outlet glaciers. {4.4.2, 4.4.3, Figures 4.14, 4.16, 4.17}

The average rate of ice loss from Antarctica likely increased from 30 [–37 to 97] Gt yr–1 (sea level equivalent, 0.08 [–0.10 to 0.27] mm yr–1) over the period 1992–2001, to 147 [72 to 221] Gt yr–1 over the period 2002–2011 (0.40 [0.20 to 0.61] mm yr–1). {4.4.3, Figures 4.16, 4.17}

In parts of Antarctica, floating ice shelves are undergoing substantial changes (high confidence). There is medium confidence that ice shelves are thinning in the Amundsen Sea region of West Antarctica, and medium confidence that this is due to high ocean heat flux. There is high confidence that ice shelves round the Antarctic Peninsula continue a long-term trend of retreat and partial collapse that began decades ago. {4.4.2, 4.4.5}

Ice sheets

Figure 4.13 | … (a) Mean surface mass balance for 1989–2004 from regional atmospheric climate modelling (Ettema et al., 2009). (b) Ice sheet velocity for 2007–2009 determined from satellite data, showing fastest flow in red, fast flow in blue and slower flow in green and yellow (Rignot and Mouginot, 2012). (c) Changes in ice sheet surface elevation for 2003–2008 determined from ICESat altimetry, with elevation decrease in red to increase in blue (Pritchard et al., 2009). (d, e) Temporal evolution of ice loss determined from GRACE time-variable gravity, shown in centimetres of water per year for the periods (a) 2003–2012, (b) 2003–2006 and (c) 2006–2012, colour coded red (loss) to blue (gain) (Velicogna, 2009).



Ice sheets

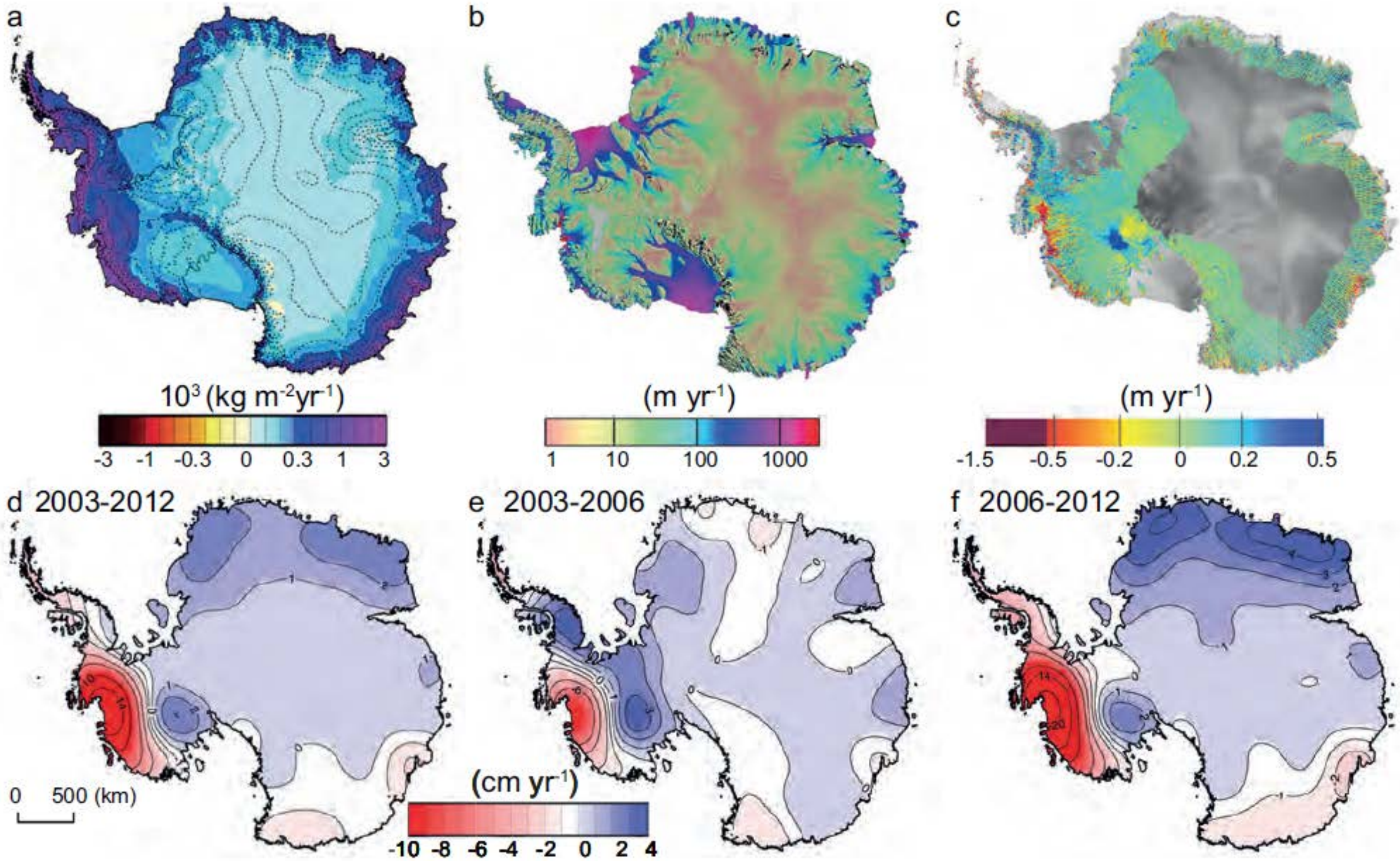
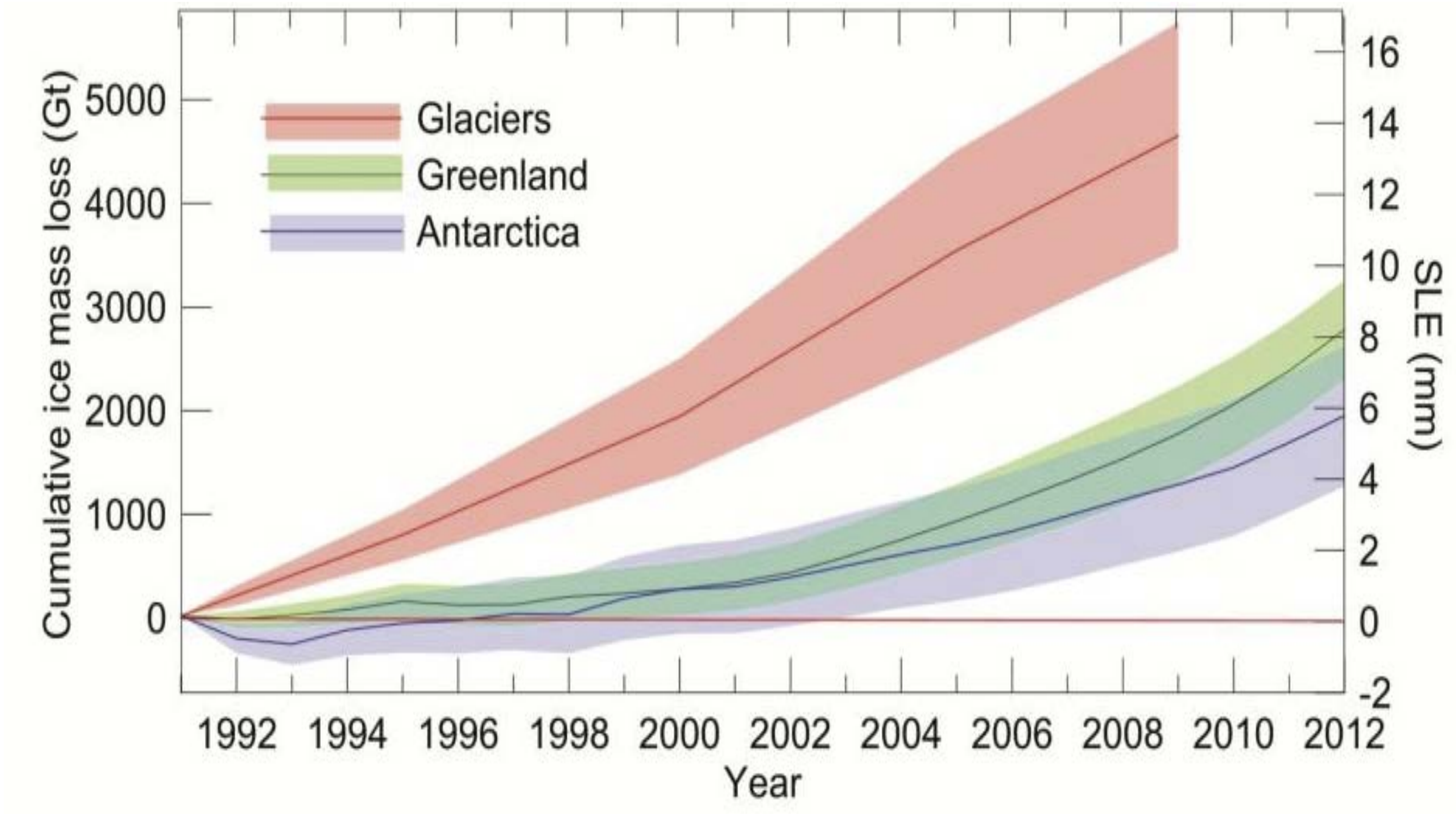
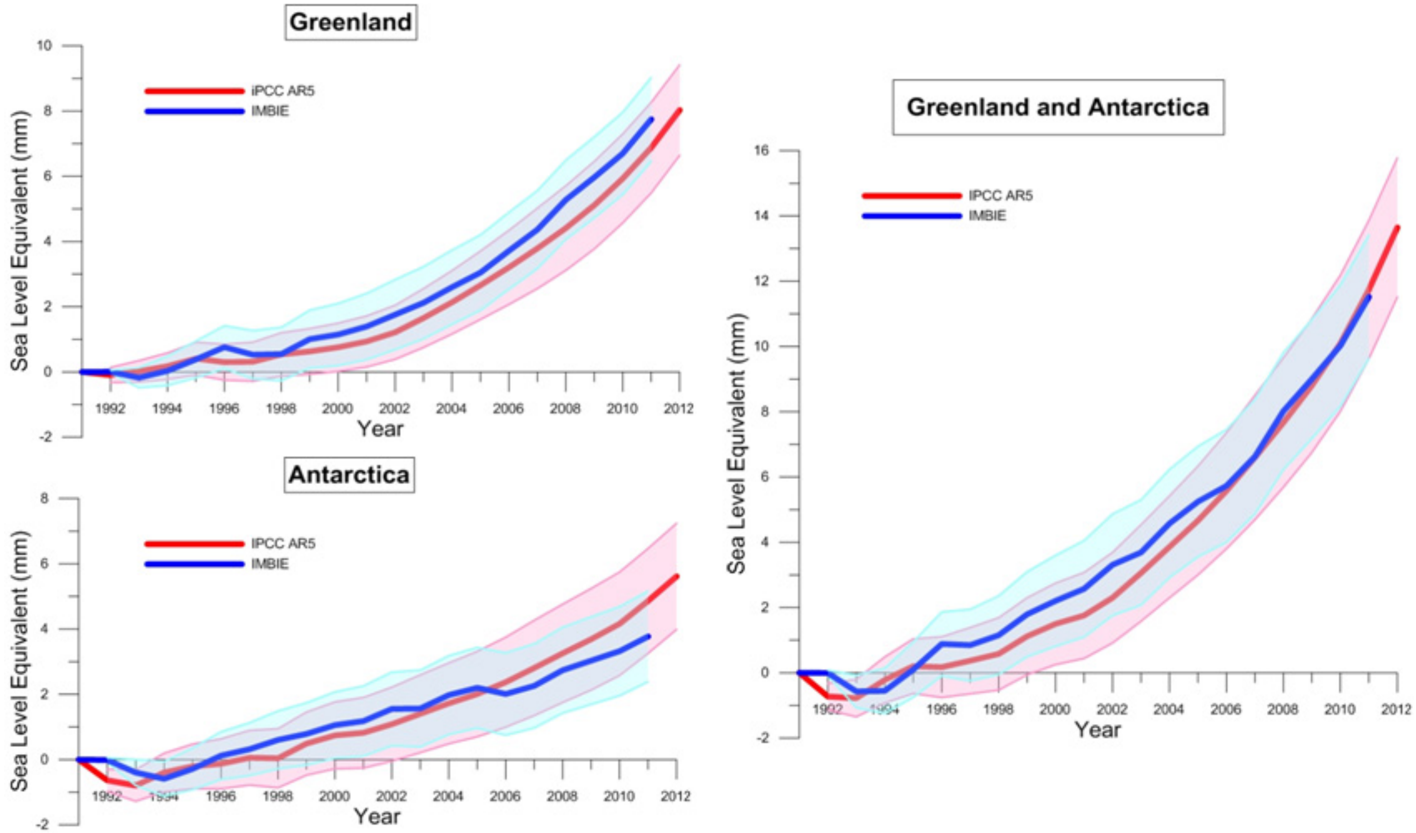


Figure 4.14 | (a) Mean surface mass balance for 1989–2004 from regional atmospheric climate modelling (van den Broeke et al., 2006). (b) Ice sheet velocity for 2007–2009 determined from satellite data, showing fastest flow in red, fast flow in blue, and slower flow in green and yellow (Rignot et al., 2011a). (c) Changes in ice sheet surface elevation for 2003–2008 determined from ICESat altimetry, with elevation decrease in red to increase in blue (Pritchard et al., 2009). (d, e) Temporal evolution of ice loss determined from GRACE time-variable gravity, shown in centimetres of water per year for the periods… red (loss) to blue (gain) (Velicogna, 2009). …

Glaciers and Ice sheets



Ice sheets



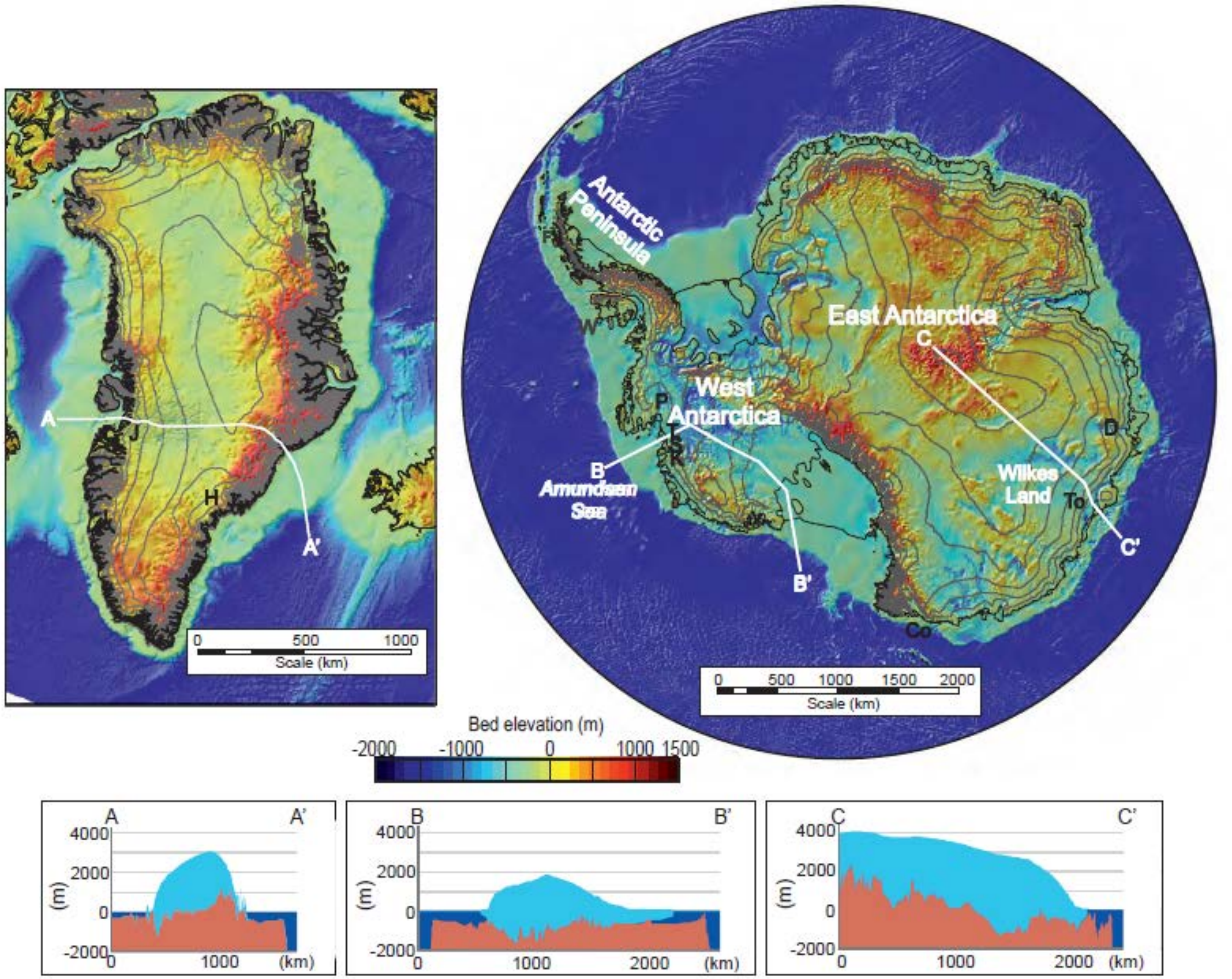
Greenland
IPCC AR5
IMBIE
Sea Level Equivalent (mm)
Year
Antarctica
IPCC AR5
IMBIE
Sea Level Equivalent (mm)
Year
Greenland and Antarctica
IPCC AR5
IMBIE
Sea Level Equivalent (mm)
Year

Ice sheets

Rapid ice sheet changes vs. Rapid dynamical changes

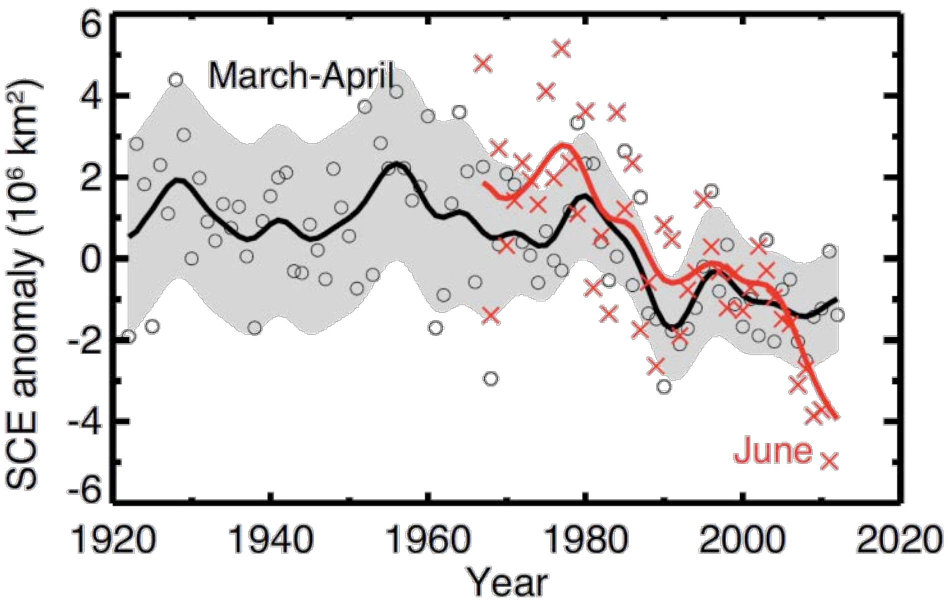
Causes

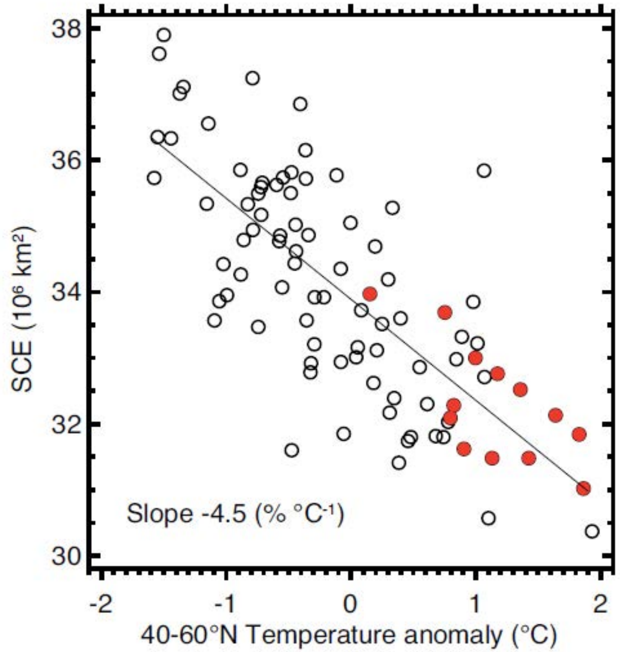
- Surface melting
- Ocean change
- Bed topography



Snow cover

Snow cover extent has decreased in the Northern Hemisphere, especially in spring (very high confidence). Satellite records indicate that over the period 1967–2012, annual mean snow cover extent decreased with statistical significance; the largest change, –53% [very likely, –40% to –66%], occurred in June. No months had statistically significant increases. Over the longer period, 1922–2012, data are available only for March and April, but these show a 7% [very likely, 4.5% to 9.5%] decline and a strong negative [–0.76] correlation with March–April 40°N to 60°N land temperature. {4.5.2, 4.5.3}





Snow cover

Station observations of snow, nearly all of which are in the Northern Hemisphere, generally indicate decreases in spring, especially at warmer locations (medium confidence). Results depend on station elevation, period of record, and variable measured (e.g., snow depth or duration of snow season), but in almost every study surveyed, a majority of stations showed decreasing trends, and stations at lower elevation or higher average temperature were the most liable to show decreases. In the Southern Hemisphere, evidence is too limited to conclude whether changes have occurred. {4.5.2, 4.5.3, Figures 4.19, 4.20, 4.21}

Freshwater ice

The limited evidence available for freshwater (lake and river) ice indicates that ice duration is decreasing and average seasonal ice cover shrinking (low confidence). For 75 Northern Hemisphere lakes, for which trends were available for 150-, 100- and 30-year periods ending in 2005, the most rapid changes were in the most recent period (medium confidence), with freeze-up occurring later (1.6 days per decade) and breakup earlier (1.9 days per decade). In the North American Great Lakes, the average duration of ice cover declined 71% over the period 1973–2010. {4.6}

Frozen Ground

Permafrost temperatures have increased in most regions since the early 1980s (high confidence) although the rate of increase has varied regionally. The temperature increase for colder permafrost was generally greater than for warmer permafrost (high confidence). {4.7.2, Table 4.8, Figure 4.24}

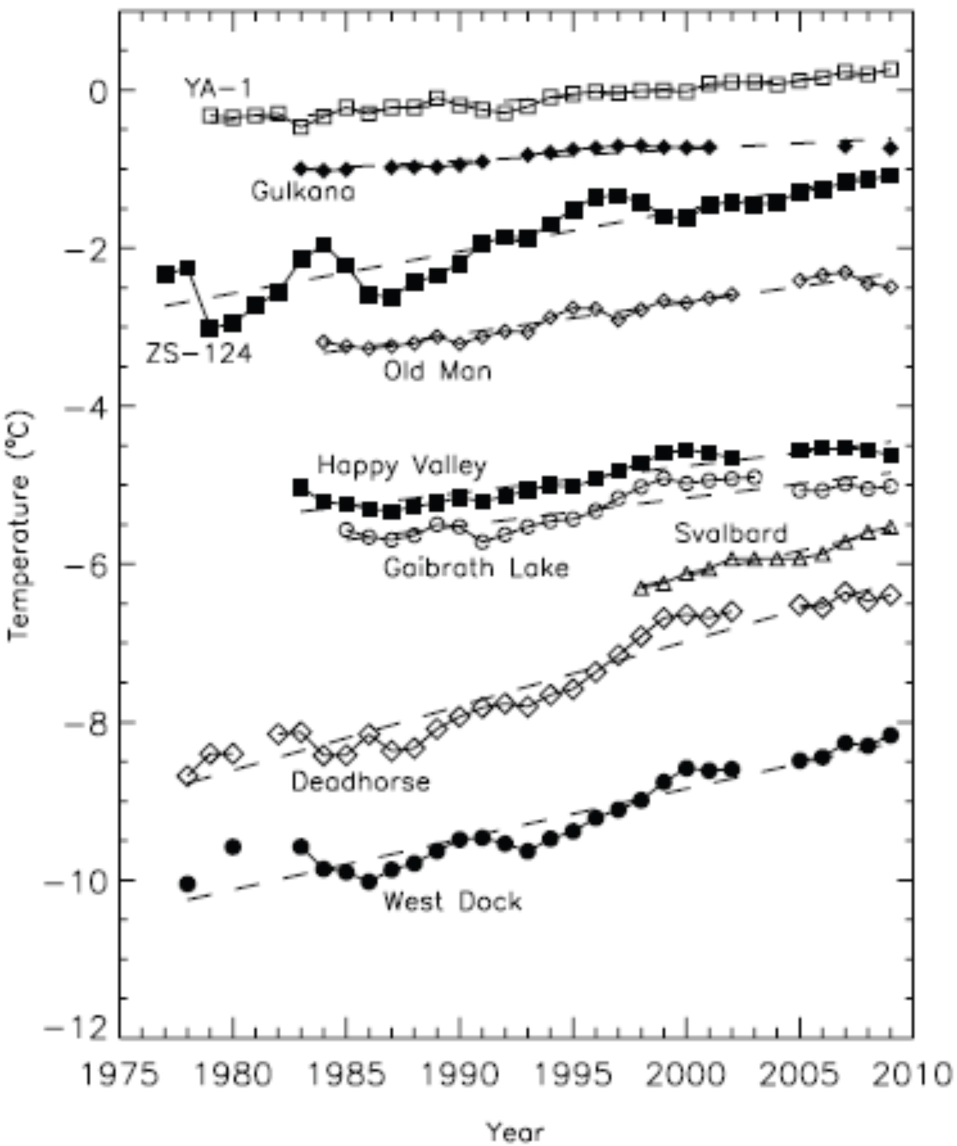
Significant permafrost degradation has occurred in the Russian European North (medium confidence). There is medium confidence that, in this area, over the period 1975–2005, warm permafrost up to 15 m thick completely thawed, the southern limit of discontinuous permafrost moved north by up to 80 km and the boundary of continuous permafrost moved north by up to 50 km. {4.7.2}

In situ measurements and satellite data show that surface subsidence associated with degradation of ice-rich permafrost occurred at many locations over the past two to three decades (medium confidence). {4.7.4}

In many regions, the depth of seasonally frozen ground has changed in recent decades (high confidence). In many areas since the 1990s, active layer thicknesses increased by a few centimetres to tens of centimetres (medium confidence). In other areas, especially in northern North America, there were large interannual variations but few significant trends (high confidence). The thickness of the seasonally frozen ground in some non-permafrost parts of the Eurasian continent likely decreased, in places by more than 30 cm from 1930 to 2000 (high confidence) {4.7.4}

Frozen Ground

Figure 4.22 | Time series of mean annual ground temperatures at depths between 10 and 20 m for boreholes throughout the circumpolar northern permafrost regions (Romanovsky et al., 2010a). Data sources are from Romanovsky et al. (2010b) and Christiansen et al. (2010). Measurement depth is 10 m for Russian boreholes….



Frozen Ground

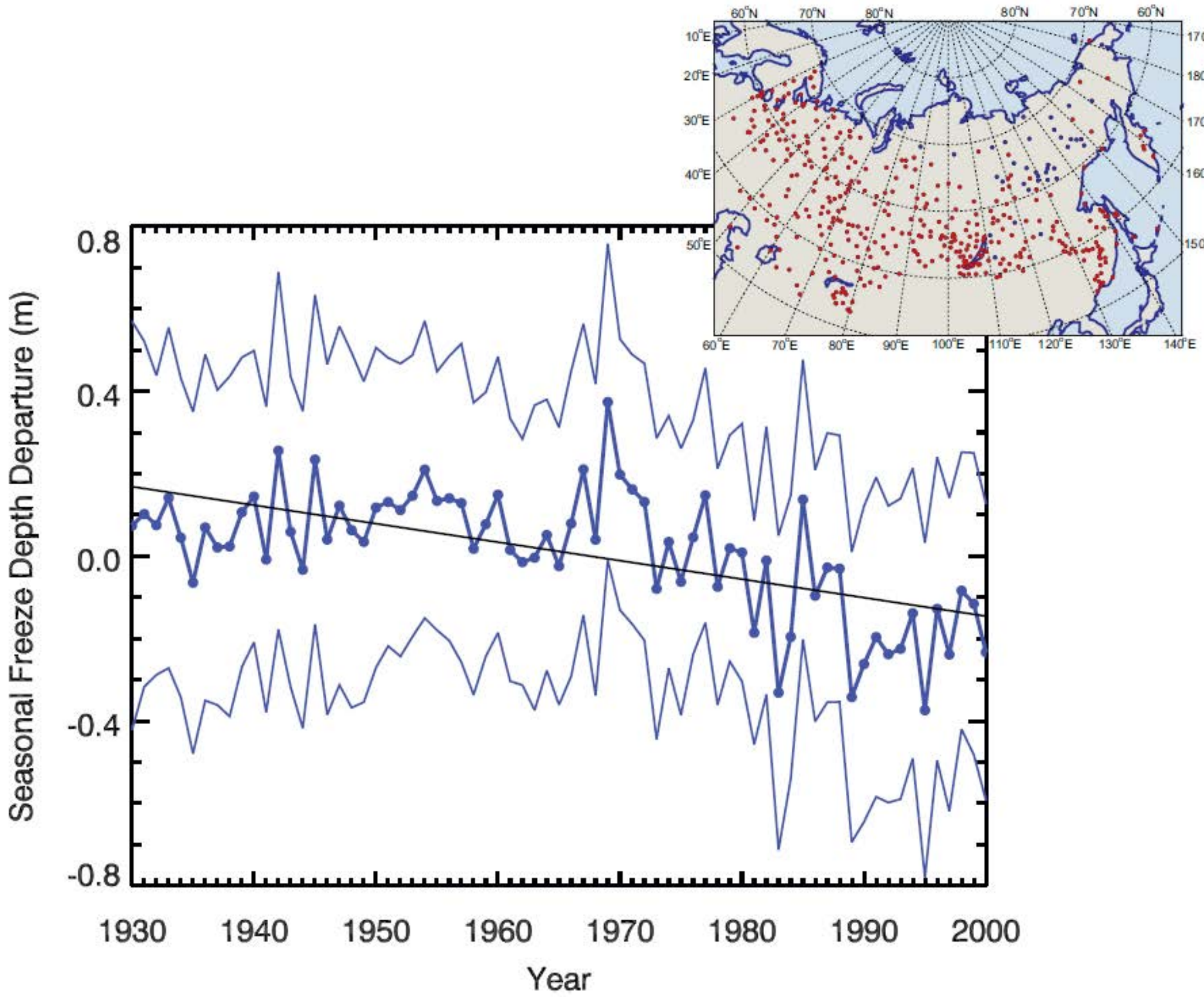
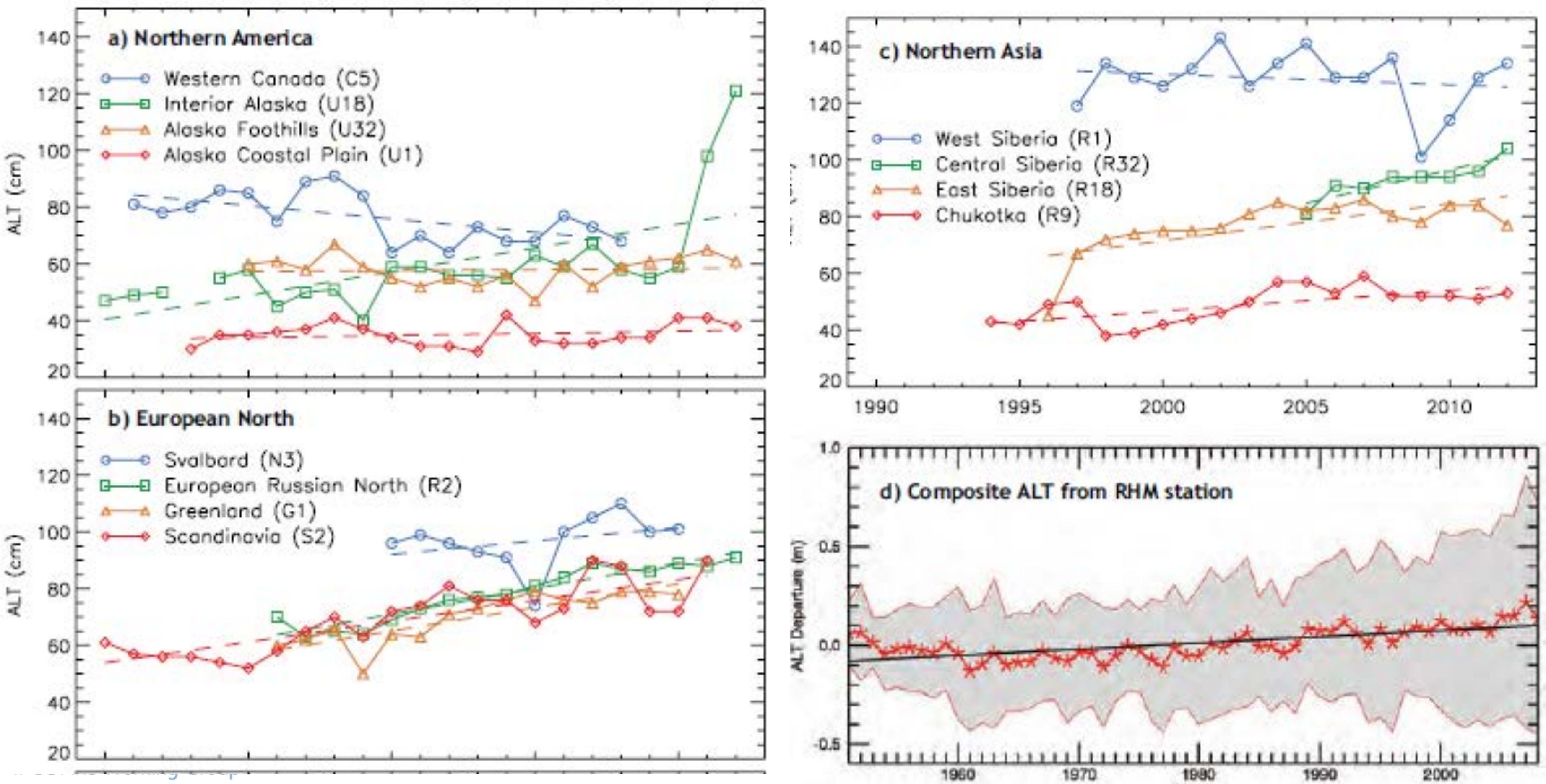


Figure 4.24 | Annual anomalies of the average thickness of seasonally frozen depth in Russia from 1930 to 2000. Each data point represents a composite from 320 stations as compiled at the Russian Hydrometeorological Stations (RHM) (upper right inset)…

Frozen Ground

Figure 4.23 | Active layer thickness from different locations for slightly different periods between 1990 and 2012 in (a) Northern America, (b) Northern Europe, and (c) Northern Asia. The dashed lines represents linear fit to each set of data. ALT data for Northern America, Northern Asia and Northern Europe were obtained from the International Permafrost Association (IPA) CALM…



Subsea permafrost

Summary

- Advances since AR4 in most areas
- Areas of continued uncertainty (permafrost, S. Hemisphere)
- Trends in the cryosphere are continued

Forward look

- Asymptotic
- Political momentum
- Insulation of system from scientific influence
- Potential for increasing complexity and diminishing clarity
- Personally favour thematic approach