lakes of Baffin Island) and Lake Hazen on Ellesmere Island, which experienced longer ICD by ~30–70 days; and (2) north European Lakes Onega and Ladoga (western Russia) by ~30–60 days, as well as smaller lakes to their south, and lakes in southern Norway. ICD for these smaller Russian and Norwegian lakes was longer by ~50–80 days in 2012/13 compared to the 2004–12 average.


Permafrost is defined as soil, rock, and any other subsurface earth material that exists at or below 0°C for two or more consecutive years. On top of the permafrost is the active layer, which thaws during the summer and freezes again the following winter. Average annual temperature of permafrost and the thickness of the active layer are good indicators of changing climate (Smith and Brown 2009). Increasing permafrost temperatures and active layer thickness caused by climate warming affect the stability of the northern ecosystems and infrastructure, and are predicted to cause the release of carbon into the atmosphere in the form of carbon dioxide (CO₂) and methane (CH₄; see section 5e). Here, permafrost temperatures and active layer thickness are reported for Alaska, Canada, Russia, and the Nordic region.

1) Permafrost temperature

In 2013, new record high temperatures at 20-m depth were measured at some permafrost observatories on the North Slope of Alaska (hereafter North Slope) and in the Brooks Range (Fig. 5.27a), where measurements began in the late 1970s and early 1980s (Fig. 5.27b). Changes in permafrost temperatures at 20-m depth typically lag about one year behind the changes in surface temperatures. The 20-m temperatures in 2013 were 0.03°C higher than in 2012 at West Dock and Deadhorse (Fig. 5.27b) on the North Slope and 0.06°C higher at Coldfoot (Fig. 5.27c) in the southern foothills of the Brooks Range. Permafrost temperatures in 2013 at the other North Slope sites were similar to those in 2012, except at Happy Valley where they were 0.06°C lower. Temperature at 20-m depth has increased between 0.28° and 0.47°C decade⁻¹ since 2000 on the North Slope (Fig. 5.27b). Permafrost temperatures in Interior Alaska (Fig. 5.27a) continued to decrease in 2013 (Fig. 5.27c), a cooling that is due to a slight decrease in mean annual air temperature and lower than normal snow depth since 2007. Consequently, temperatures in 2013 at

Fig. 5.26. (a) Freeze-up, (b) break-up, and (c) ice cover duration anomalies (in days) in the 2012/13 ice season relative to the 2004–12 average. Data are from the NOAA IMS (Helfrich et al. 2007) 4-km product, which incorporates a wide variety of satellite imagery, derived mapped products, and surface observations. Freeze-up and break-up dates, and ice duration were derived at the pixel level from this product.
some sites in Interior Alaska were lower than those located farther north, e.g., temperatures at College Peat and Birch Lake are now lower than at Old Man and Chandalar Shelf in the Brooks Range (Fig. 5.27).

In 2012/13, temperatures in the upper 25 m of ground at Alert, northernmost Ellesmere Island, Canada, were among the highest recorded since measurements began in 1978 (Fig. 5.28). At a depth of 15 m in borehole BH5, temperature has increased by ~1.4°C decade\(^{-1}\) since 2000, which is almost 1°C higher than the rate for the entire record. Even at a depth of 24 m, temperature has increased since 2000 at a rate approaching 1°C decade\(^{-1}\). It should be noted, however, that over the last two years, the rate of temperature increase has slowed and there has been even a slight cooling at 15-m depth; this is likely a response to a decrease in air temperatures between 2010 and 2012. Temperatures in the warm permafrost in the central Mackenzie River valley in northwestern Canada continue to increase, but at a much slower rate that has slowed further in the last decade (Fig. 5.28). At depths of 10–12 m, the permafrost temperature at Norman Wells and Wrigley has risen by 0.07°–0.2°C per decade since 2000. A recent study by James et al. (2013) found that significant degradation of permafrost has occurred since 1964 along the Alaska Highway corridor in the southern Yukon and northern British Columbia. As a result, the southern limit of permafrost appears to have shifted northward by at least 25 km.

Permafrost temperature has increased by 1°–2°C in northern Russia during the last 30–35 years (Romanovsky et al. 2010b), similar to that observed in northern Alaska and the Canadian high Arctic. In the Polar Ural, for example, temperatures at 15-m depth have increased by ~0.5°C decade\(^{-1}\) since the late 1980s at colder permafrost sites (Fig. 5.29, sites ZS-124, R-92, and R57). Less warming has been observed at warm permafrost sites and a slight cooling has occurred since 2009 (Fig. 5.29, sites ZS-124 and KT-16a).
There are limited long-term permafrost temperature records for the Nordic area. A few of these were initiated at the end of the 1990s and since then temperature has increased at rates of 0.4°–0.7°C decade⁻¹ in the highlands of southern Norway, northern Sweden, and Svalbard, with the largest warming in Svalbard and in northern Scandinavia (Isaksen et al. 2011; Christiansen et al. 2010). In western Greenland, permafrost temperatures are relatively warm, from −1° to −3°C (Christiansen et al. 2010). In eastern Greenland, the first full year of permafrost temperatures in 10 recently established boreholes (depth range of 2–18 m) were obtained in summer 2013, and the permafrost temperature was found to be −6° to −7°C.

2) Active layer thickness

Decadal trends in the active layer thickness (ALT) vary by region (Shiklomanov et al. 2012). In 2013, a majority of sites in Alaska reported higher ALT values relative to the 1995–2013 average, consistent with an exceptionally warm summer (see section 5b). On the North Slope, for example, ALT in 2013 was, on average, 11% higher than the 1995–2013 average of 0.47 m. The 2013 average ALT is 6% higher than in 2012 and on par with the 20-year maximum recorded in 1998. In Interior Alaska, ALT has been relatively unchanged since the maximum value reached in 2007, and 2013 values were slightly lower than in 2012. ALT in 2013 was similar to 2012 at sites on the Seward Peninsula, westernmost Alaska mainland.

A slight decrease in ALT in 2013 was observed in west Siberia a year after the highest values in the observational record were observed in 2012. This does not alter an observed thickening trend in west Siberia over the last six years. The 2013 ALT values are 8% higher than the 1995–2013 mean of 1.1 m. A more or less continuous thickening of the active layer has been reported at locations in the Russian European North, although ALT in 2013 was 6% lower than the record maximum of 2012. Central Siberian locations also report slightly lower ALT values in 2013 than in 2012. ALT in eastern Siberia in 2013 was similar to 2012, 10% lower than in 2011, and all sites had lower ALT than the 1996–2013 average of 0.64 m. In 2013, ALT values in Chukotka (Russian Far East) were about 2% higher than in 2012, marking a slight increase in ALT during 2011–13 following a sharp decline in 2008–10.