from 3.71 m in 1980 to 2.46 m in 2000, a decrease of 1.25 m (Rothrock et al. 2008). Maslanik et al. (2007) generated a proxy ice-thickness record for 1982–2007 by combining satellite estimates of sea-ice age and thickness, and the record indicates significant thinning between 1982 and 2007. A reduction of modal and mean sea ice thicknesses in the region of the North Pole of up to 53% and 44%, between 2001 and 2007, has been observed by Haas et al. (2008) using helicopter-borne electromagnetic ice-thickness profilers. Using satellite radar altimetry data, covering the Arctic Ocean up to 81.5°N, Giles et al. (2008) observed that after the melt season of 2007, the average sea-ice thickness was 0.26 m below the 2002/03 to 2007/08 average. In contrast to the central Arctic, measurements of the seasonal and coastal ice cover do not indicate any statistically significant change in thickness in recent decades (Melling et al. 2005; Haas 2004; Polyakov et al. 2003), indicating that the thinning of the ice cover is primarily the result of changes in perennial ice thickness.

e. *Land*—D. A. Walker, U. S. Bhatt, M. K. Raynolds, J. E. Comiso, H. E. Epstein, and G. J. Jia

1) Vegetation

Models have predicted that the retreating sea ice (see section 5d) should affect the temperature and ecosystems of adjacent lands (e.g., Lawrence et al. 2008). Time series of sea-ice area and land temperatures, as well as an index of greening, were investigated for trends and variability during the period 1982–2007 along the coastlines of 14 Arctic seas (Fig. 5.13). Temporal analyses of these regional time series (not shown) consistently indicate that higher land-surface temperatures and higher NDVI values correspond to below-average sea-ice concentration (Bhatt et al. 2008, 2009, manuscript submitted to *Earth Interactions*).

The trend analysis shows that coastal sea ice declined in all regions, with a decrease of 25% for the Northern Hemisphere as a whole (Fig. 5.13, top blue bar). The largest declines were along the northern Beringia region, including the west Chukchi, east Chukchi, and east Siberia Seas. This portion of the Arctic saw large areas of summer ice retreat in 2005 and 2007.

Land temperatures as measured by the summer warmth index (sum of the monthly mean temperatures that are above freezing) increased 24% for the Northern Hemisphere as a whole (Fig. 5.13, top red bar). However, the coastal areas of the North America Arctic have experienced a 27% increase in land temperatures, while Eurasia experienced only a 16% increase. The largest increases occurred in the Beringia region (east Siberia, west Chukchi, west Bering, and east Chukchi) and in the Greenland and Baffin Island regions (Greenland Sea, Baffin Bay, and Davis Strait). The smallest increases were seen along

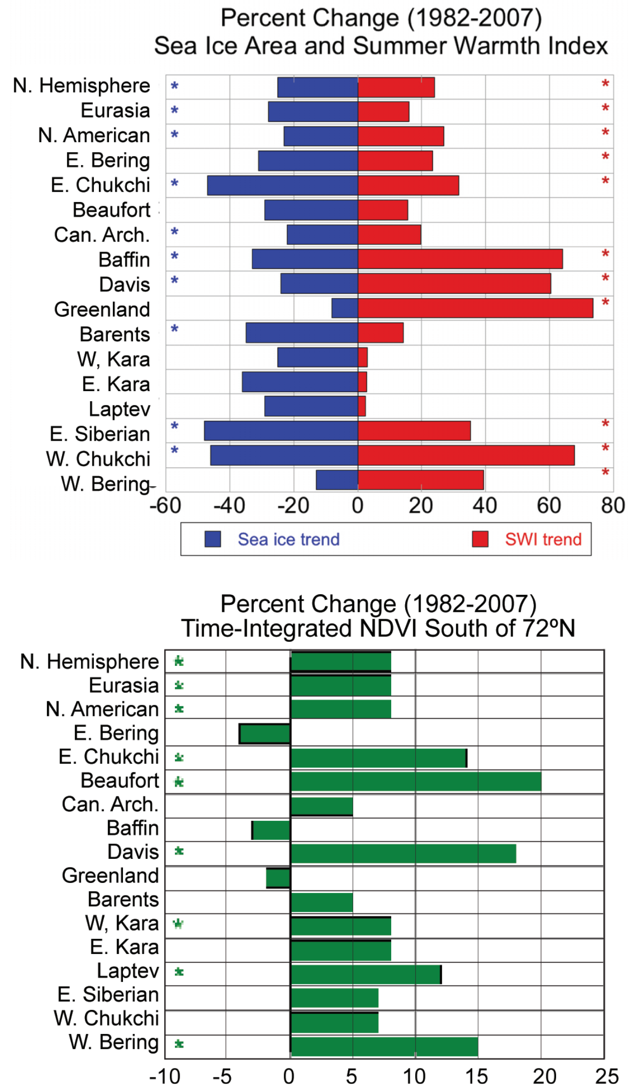

Fig. 5.13. (top, blue bars) Percentage change in sea-ice area in late spring (when the long-term mean 50% concentration is reached) during 1982–2007 along the 50-km-seaward coastal margin in each of the major seas of the Arctic using 25-km-resolution SSMI passive microwave Bootstrap sea-ice concentration data (Comiso and Nishio 2008). (top, red bars) Percentage change in the summer land-surface temperature along the 50-km-landward coastal margin as measured by the SWI [sum of the monthly mean temperatures above freezing (°C mo)] based on AVHRR surface-temperature data (Comiso 2003). (bottom, green bars) Percentage change in greenness for the full tundra area south of 72°N as measured by the TI-NDVI based on biweekly GIMMS NDVI (Tucker et al. 2001). Asterisks denote significant trends at $p < 0.05$. Based on Bhatt et al. (2008).

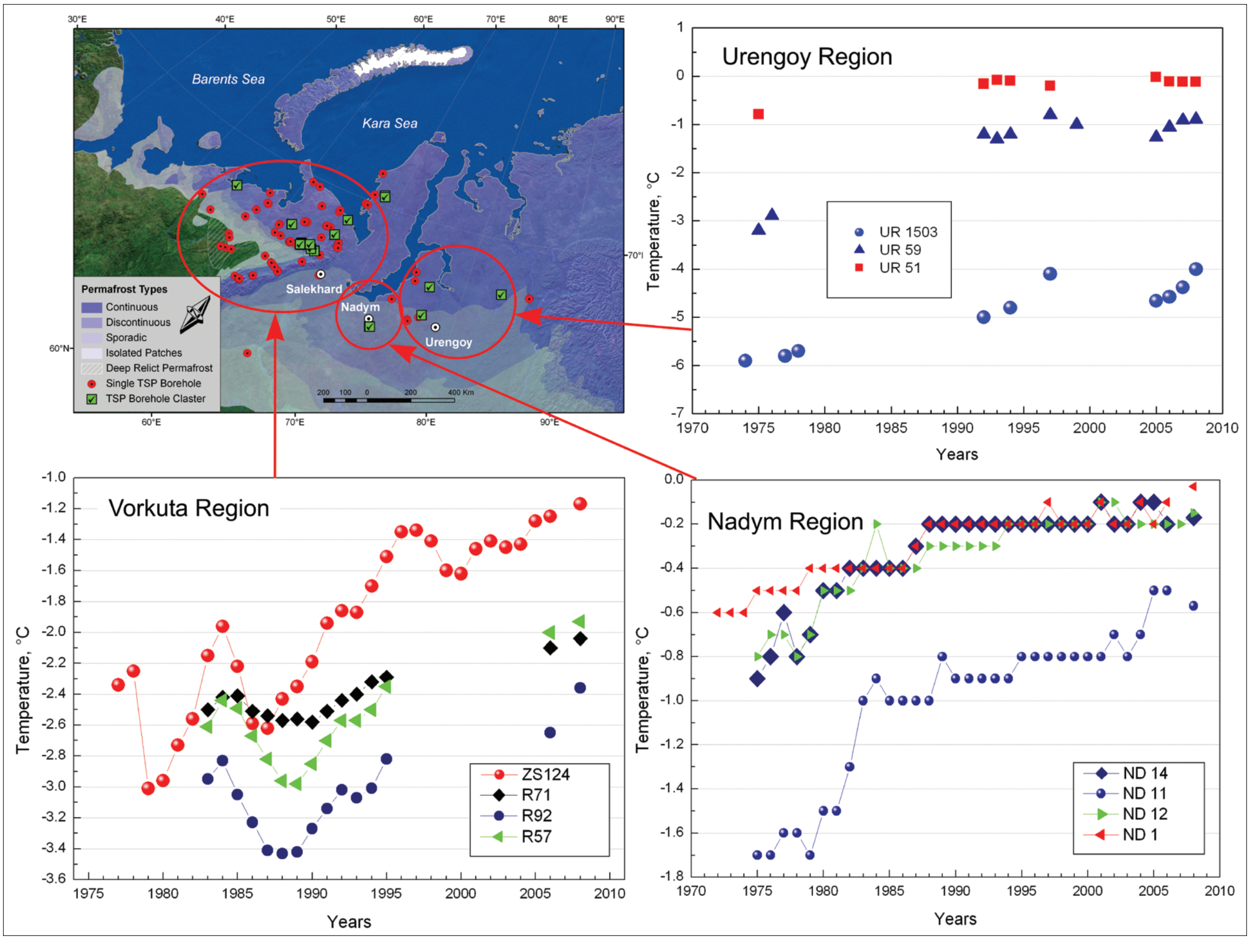

Fig. 5.14. (top left) Location of the long-term MIREKO and the Earth Cryosphere Institute permafrost observatories in northern Russia. (bottom left) Changes in permafrost temperatures at 15-m depth during the last 20 to 25 years at selected stations in the Vorkuta region (updated from Oberman 2008). (top right) Changes in permafrost temperatures at 10-m depth during the last 35 yr at selected stations in the Urengoy and Nadym (bottom right) regions (updated from Romanovsky et al. 2008).

the northern coast of Russia (Laptev Sea, east Kara Sea, and west Kara Sea).

Greenness was determined using the TI-NDVI derived from the GIMMS data. TI-NDVI is an index of the productivity of the vegetation each summer that is derived from Earth's reflectance in the visible and near-infrared portions of the spectrum. The TI-NDVI analysis was limited to the area south of 72°N (covers primarily the low Arctic) because of a discontinuity in the GIMMS data at this latitude. TI-NDVI increased 8% for the Arctic as a whole (Fig. 5.13, top green bar) but was variable. The largest increase was along the Beaufort Sea coast (20%). Other large increases occurred adjacent to the Davis Strait and the east Chukchi and west Bering Seas. Smaller increases occurred in much of northern Russia (Barents, Kara, east Siberian, and west Chukchi Seas), generally where summer temperature increases were lower. A few nonsignificant negative trends occurred in the east Bering Sea, Baffin Bay, and Greenland Sea. The NDVI changes noted here are in general agreement with other analyses of NDVI trends in the Arctic (Jia et al. 2003; Goetz et al. 2005; Verbyla 2008; Raynolds et al. 2008) and ground observations (Tape et al. 2006; Walker et al. 2008; Epstein et al. 2008).

2) Permafrost—V. Romanovsky, N. Oberman, D. Drozdov, G. Malkova, A. Kholodov, and S. Marchenko

Observations show a general increase in permafrost temperatures during the last several decades in Alaska (Romanovsky et al. 2002, 2007; Osterkamp 2008), northwest Canada (Couture et al. 2003; Smith et al. 2005), Siberia (Oberman and Mazhitova 2001; Oberman 2008; Drozdov et al. 2008; Romanovsky et al. 2008), and northern Europe (Isaksen et al. 2000; Harris and Haeberli 2003).

Most of the permafrost observatories in Alaska show a substantial warming during the last 20 years.