(not shown). This warm, southerly flow accelerates snowmelt over Alaska and eastern Siberia, and ice melt in the Bering Sea and Sea of Okhotsk. By late May, Pacific air warmed further as it advected over high-latitude tundra that was continuously exposed to intense solar radiation, which lead to an early onset of melt. Therefore, an early and prolonged melt season amplifies late summer sea ice retreat, especially in the western Arctic where the ice pack has become younger and thinner (Rigor and Wallace 2004).

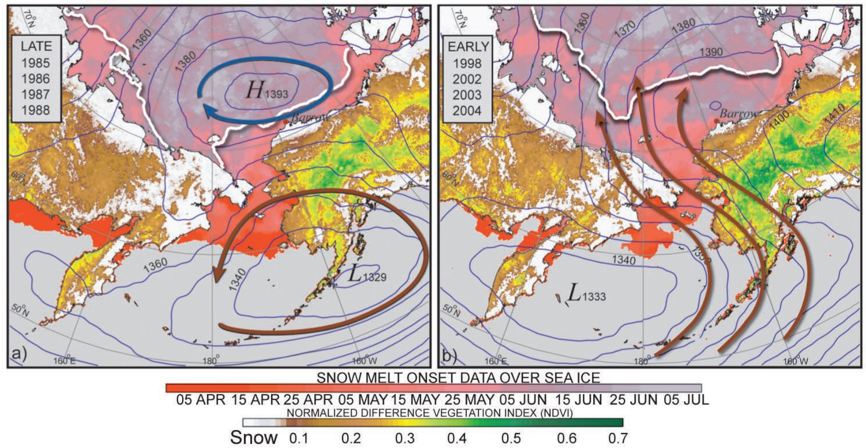

FIG. 5.4. Environmental conditions over the western Arctic averaged for years with (a) minimum and (b) maximum sea ice retreat. The extent of late summer ice retreat, defined as the southern limit of >50% mean ice concentration during 16–30 September, is shown as a bold white line. Thin blue lines depict 10-m contours of mean Mar–May 850-hPa geopotential heights from the NCEP–NCAR 40-yr reanalysis project. Generalized circulation patterns are shown with bold vectors. Mean melt onset dates over sea ice (Belchansky et al. 2004b) are color shaded for areas where ice concentrations averaged > 50% during the period 16–31 May. Vegetation greenness is depicted during 16–31 May by the mean maximum NDVI [derived from Global Inventory Modelling and Mapping Studies (GIMMS) NDVI-d and NDVI-n16 datasets].

III) GREENLAND—J. E. Box[7]

Coastal station temperature records around Greenland indicate warming trends since the early 1980s that are large in the context of longer-term records (1873–2004). This recent warming has brought once anomalously cold Greenland regional temperatures in phase with the global warming pattern. Considering the last 55-yr period (1950–2004) when data are available from a collection of stations around the circumference of the ice sheet, the years of 2003 and 2004 were among the warmest, and were possibly the warmest, years on record (Table 5.1). The 1930s and 1940s also represent an exceptionally warm period in the long-term record. However, since 1895 at Tasiilaq (Nuuk), 2003 was the warmest (warmest) and 2004 the 9th warmest (20th warmest) of this 110-yr record. Therefore, regional variability in warming over the annual time frame is apparently large. Despite this variability, these recent increases in temperature are coherent among the entire collection of more than 15 Greenland climate stations. The observed warming has certainly contributed to increased rates of melting, and placed the Greenland ice sheet as a significant contributor to global sea level rise (Box et al. 2004).

Seasonally, the majority of warming has been observed during the winter and spring. Summer and autumn trends have been smaller, owing to the

TABLE 5.1. The observed ranking of 2004 and 2003 as anomalously warm years around Greenland for stations over the 1950–2004 period.

Station	Latitude, longitude	Region	Year and ranking as warmest
Prins Christian Sund	60.0°N, 43.2°W	South	2004 (1), 2003 (2)
Egedesminde	68.7°N, 52.8°W	Central west	2004 (2), 2003 (1)
Tasiilaq	65.6°N, 37.6°W	Southeast	2004 (2), 2003 (1)
Nuuk	64.2°N, 51.8°W	Southwest	2004 (5), 2003 (7)
Danmarkshavn	76.8°N, 18.7°W	Northeast	2004 (9), 2003 (3)

suppression of positive trends from latent heat sinks during snow- and ice-melt periods. Nonetheless, winter warming trends affect the intensity of summer melting owing to changes in the cold content of seasonal snow, which must be melted off before ablation of underlying ice takes place.

The Polar version of the fifth generation Pennsylvania State University (PSU)–NCAR Mesoscale Model (MM5) (Bromwich et al. 2001; Cassano et al. 2001), run in data assimilation mode, provides climate information for the ice-covered interior of Greenland over a longer time period and with a broader spatial coverage than that available from automated weather stations. Annual reconstructions of 2-m air temperature are compared within 1-K root-mean-square error (rmse) of observations from an independent network of automatic weather stations on the inland ice (Steffen and Box 2001). Therefore, a 17-yr set (1988–2004) of Polar MM5 output provides a means for assessing ice sheet melt rates, meltwater discharge, and sea level contributions.

A trend of warming temperatures around Greenland that began in the early 1980s has continued through 2004. In terms of annual mean temperatures for the ice sheet as a whole, the warming in 2004 was the second highest, ranking behind only 1998. Spatially, the warming signal has been concentrated along the western margin and the topographic divide of the ice sheet (Fig. 5.5a), where the maximum change in temperature exceeded 6 K. The annual mean anomalies in 2004 indicate that temperatures were up to 3.6 K above the 17-yr average, with no grid points over the ice sheet with a negative temperature anomaly for 2004. In concert with this warming was a widespread increase in the duration of melting (Fig. 5.5b). In light of the observations that demonstrate ice sheet dynamical flow increases when melt water is available to lubricate the bed (Zwally et al. 2002), the ice sheet flow rate likely continued to increase in 2004, and the ice sheet remains in a state of net mass loss with significant (~0.2 mm yr^{-1}) global, eustatic sea level contributions (Box et al. 2004).

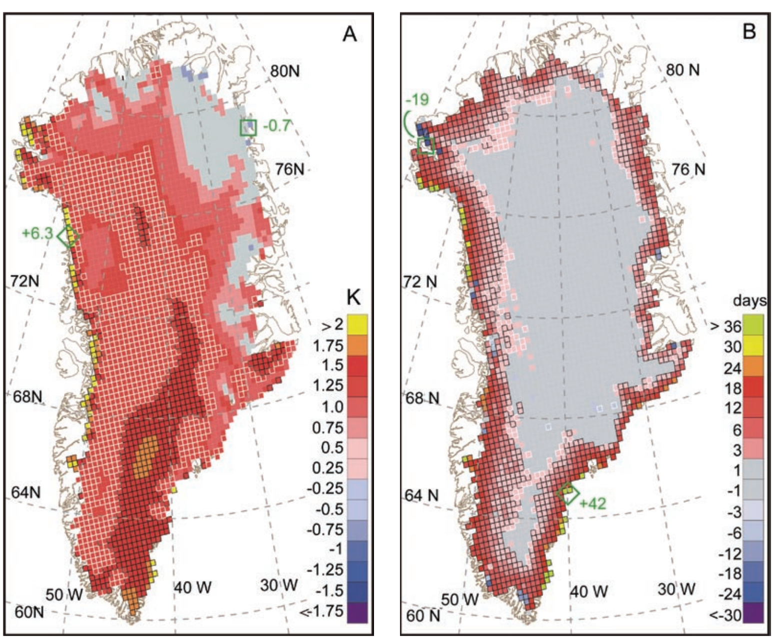

Fig. 5.5. The spatial pattern of change over the Greenland ice sheet (1988–2004) from the Polar MM5 data assimilation output: (a) annual temperature and (b) number of melt days. Student's *t* test statistical significance above the 85% (95%) confidence interval is indicated by white (black) outlined grid cells, respectively. Locations of maximum and minimum trend values are indicated by green symbols.

b. Antarctic

i) Surface climate—A. M. Waple[19] and E. Rignot[32]

Surface air temperatures across the majority of stations on the Antarctic continent were above average in 2004, with the largest temperature trends over the last several decades measured along the Antarctic Peninsula (Fig. 5.6). The observed trends across the rest of the continent have been mixed, with interior stations such as Amundsen–Scott (South Pole) and Vostok showing small, insignificant trends in surface temperature. It is, perhaps, Antarctica's apparent continent-wide temperature stability that is remarkable in the context of global warming. It is only the Antarctic Peninsula (4% of the continental area) that shows a significant warming trend. The peninsula is also the warmest area of the continent on average, rising above freezing for 2 months yr^{-1} on its warmest coast (BAS 2004). Due to the sparsity of stations on Antarctica, the lack of long-term stations, and the high interannual temperature variability, it is impossible to state with certainty, whether the Antarctic continent is warming or cooling overall.

Trends in sea ice in the Southern Hemisphere have generally increased since the late 1970s (Fig. 5.7), with above-average values of sea ice extent in 2004. However, the seasonal and spatial variability have been extreme in the Southern Hemisphere, with ice shelf and sea ice retreat occurring in