STATE OF THE CLIMATE IN 2020

THE ARCTIC

M. L. Druckenmiller, T. Moon, and R. Thoman, Eds.

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STATE OF THE CLIMATE IN 2020
The Arctic

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The crew of the research icebreaker Polarstern inspects the ice anchors after a sea ice fracturing event at the early stages of the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) experiment.

The Arctic is one chapter from the *State of the Climate in 2020* annual report and is available from https://doi.org/10.1175/BAMS-D-21-0086.1. Compiled by NOAA's National Centers for Environmental Information, *State of the Climate in 2020* is based on contributions from scientists from around the world. It provides a detailed update on global climate indicators, notable weather events, and other data collected by environmental monitoring stations and instruments located on land, water, ice, and in space.
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5. Table of Contents

List of authors and affiliations S266
a. Overview S269
b. Surface air temperature S270
1. Mean annual surface air temperature over the terrestrial Arctic S271
2. Seasonal air temperature patterns S271

Sidebar 5.1: Wildland fires in the high northern latitudes S274
c. Sea surface temperature S277
d. Sea ice S279
1. Sea ice extent S279
2. Sea ice thickness and volume S281
3. Ice age S282

e. Greenland ice sheet S283
f. Terrestrial snow cover S287
g. River discharge S290
h. Permafrost S293
1. Permafrost temperatures S294
2. Active layer thickness S296

i. Tundra greenness S297
j. Ozone and ultraviolet radiation S299
1. Ozone S300
2. Ultraviolet radiation S302

Sidebar 5.2: Assessing 15 years of Arctic Observing Network contributions to tracking key Arctic climate variables S304
Acknowledgments S307
Appendix 1: Chapter 5 – Acronyms S309
References S311

*Please refer to Chapter 8 (Relevant datasets and sources) for a list of all climate variables and datasets used in this chapter for analyses, along with their websites for more information and access to the data.

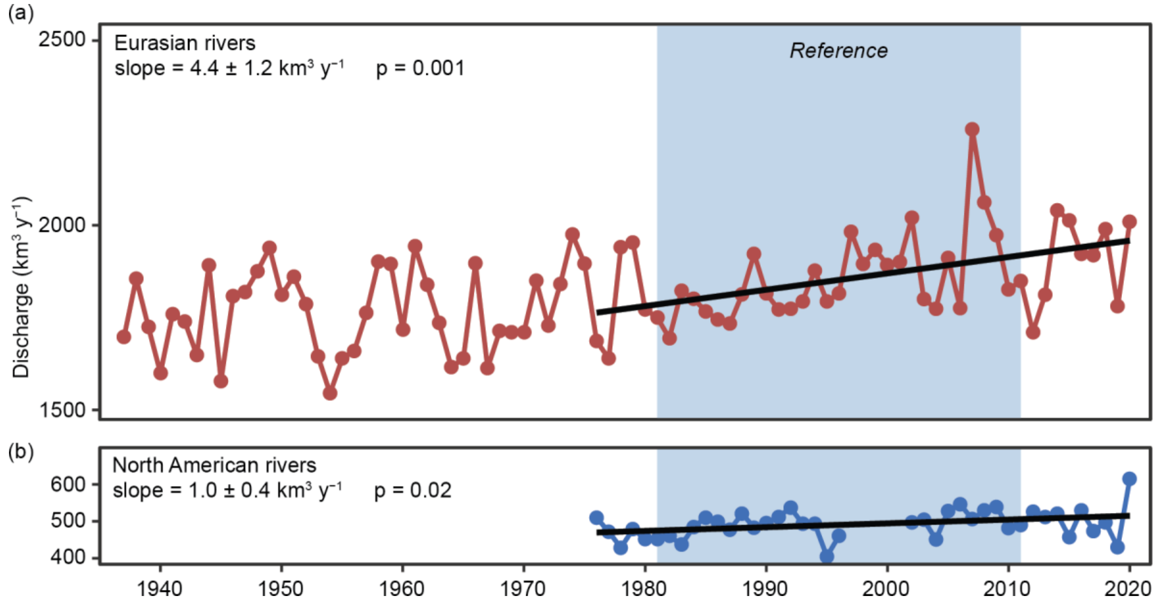

Fig. 5.20. Long-term trends in annual discharge (km^3 yr^{-1}) for (a) Eurasian and (b) North American Arctic rivers. Gaps in the North American rivers time series span from 1996 through 2001 due to missing Yukon data from 1996 to 2001 and missing Mackenzie measurements in 1997 and 1998. Reported slopes are for the period 1976–2020. Note the different scales for the (a) Eurasian and (b) North American river discharge.

h. Permafrost—S. L. Smith, V. E. Romanovsky, K. Isaksen, K. E. Nyland, A. L. Kholodov, N. I. Shiklomanov, D. A. Streletskiy, L. M. Farquharson, D. S. Drozdov, G. V. Malkova, and H. H. Christiansen

Permafrost refers to Earth materials (e.g., bedrock, mineral soil, organic matter) that remain at or below 0°C for 2 years or longer and underlies extensive regions of the high-latitude landscape (Brown et al. 1997). Overlying the permafrost is the active layer, which thaws and refreezes annually. Permafrost, especially where it contains large volumes of ice, can play a critical role in the stability of Arctic landscapes. Warming of permafrost, active layer thickening, and ground ice melt cause changes in surface topography, hydrology, and landscape stability, thus having implications for the integrity of the Arctic infrastructure and ecosystems (Romanovsky et al. 2017; Bjella 2019). Changes in permafrost conditions can also affect the rate of release of carbon dioxide and methane to the atmosphere, with the potential to accelerate global warming (Schuur 2020).

Permafrost conditions respond to shifts in the surface energy balance through a combination of interrelated changes in ground temperature and active layer thickness (ALT). Ground temperatures fluctuate seasonally near the surface, while below the depth of seasonal temperature variation, ground temperature reflects longer-term changes in climate. Long-term changes in permafrost temperatures are driven by changes in air temperature (Romanovsky et al. 2017); however, permafrost temperature trends show local variability due to other important influences such as snow cover, vegetation characteristics, and soil moisture. Monitoring sites across the Arctic (Fig. 5.21) have been recording ground temperature in the upper 30 m for up to 5 decades, providing critical data on changes in permafrost stability. Observed changes in ALT relate to shorter-term (year-to-year) fluctuations in climate and are especially sensitive to changes in summer air temperature and precipitation.

Travel restrictions in 2020 due to COVID-19 limited data collection in some regions. For boreholes that have data loggers, the lack of site visits may only delay data acquisition with little impact on record continuity. For data collected manually, including ALT, there is a loss of data for 2020.

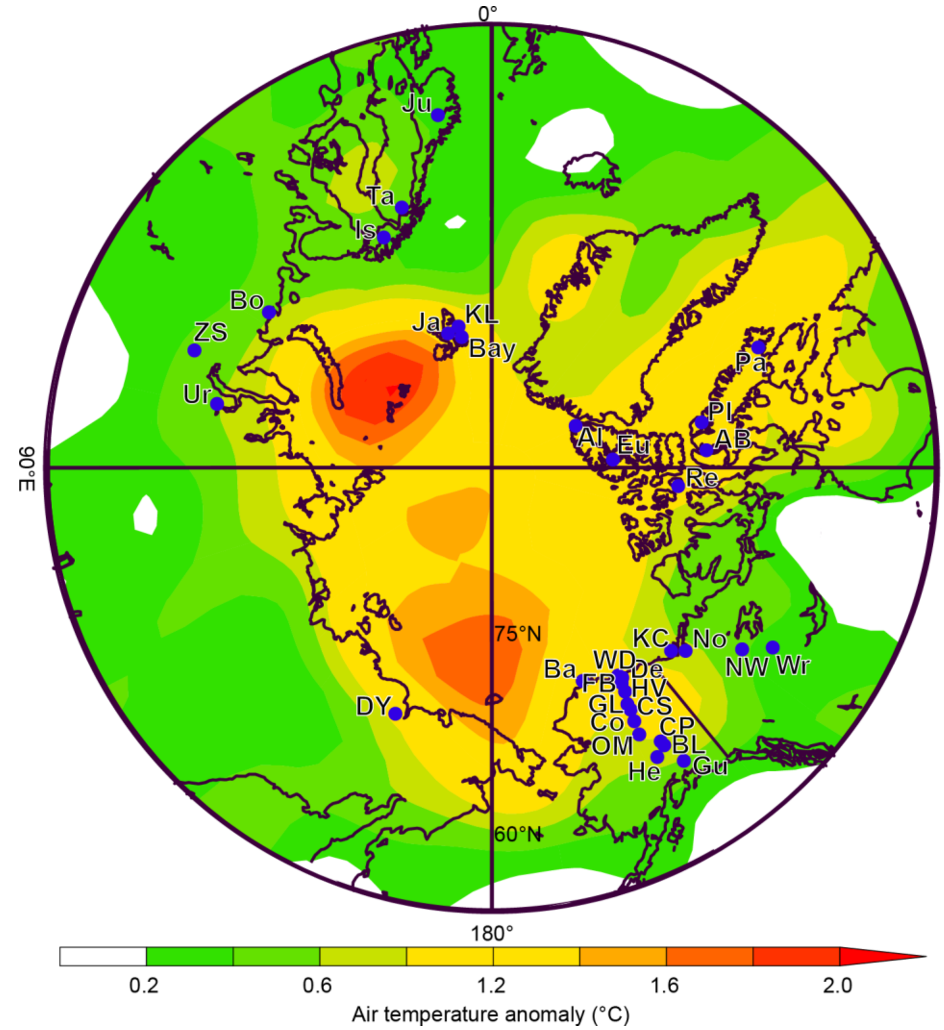

Fig. 5.21. Location of the permafrost temperature monitoring sites (for which data are shown in Fig. 5.22), superimposed on average surface air temperature anomalies (°C) during 2000–20 (with respect to the 1981–2020 mean) from the NCEP-reanalysis (Kalnay et al. 1996). Reanalysis data provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado (www.esrl.noaa.gov/psd/). See Table 5.2 for site names. Information about these sites is available at http://gtnpdatabase.org/, http://permafrost.gi.alaska.edu/sites_map, and https://www2.gwu.edu/~calm/.

1) Permafrost temperatures

Observed increases in permafrost temperatures since the 1980s were generally greater in colder permafrost at higher latitudes, where the largest increases in air temperature were observed (Figs. 5.21, 5.22). Permafrost temperatures in 2020 (where available) were higher than those observed in 2019 (except some sites in the Barents region) and the highest on record at a majority of the observation sites (Fig. 5.22; Table 5.2). In northern Alaska, for example, temperatures in 2020 were up to 0.1°C higher than in 2019 and in the Alaskan interior the 2020 temperature at one site (Old Man) was >0.1°C higher than in 2019, about 1.4°C higher than in 1985 (Figs. 5.22a,b). At Alert in the Canadian High Arctic, permafrost temperatures were also higher in 2020, and 1.4°C higher than at the start of monitoring in 1978 (Fig. 5.22c).

At some sites, recent increases in the rate of permafrost warming have also been observed (Fig. 5.22; Table 5.2). In the Canadian High Arctic, warming rates for 2000–20 were greater than that for the entire 40-year record (Fig. 5.22c; Table 5.2). Throughout the Arctic, the response of permafrost with temperatures close to 0°C (i.e., warm permafrost sites) is slower (generally <0.3°C decade^{-1}) due to latent heat effects related to melting ground ice. Warming at some sites with cold continuous permafrost, however, has been more rapid. For example, in the Beaufort-Chukchi region, permafrost temperatures in northern Alaska have increased by 0.35° to 0.81°C decade^{-1}

(Fig. 5.22a; Table 5.2). Over a shorter record in northeastern Siberia, permafrost temperatures have increased by 0.4°C decade^{-1}, similar to the twenty-first century rate for northern Alaska (0.4° to 0.7°C decade^{-1}).

In the Nordic region, permafrost warming reported by Isaksen et al. (2011) and Etzelmüller et al. (2020) is continuing (Fig. 5.22d). The longest records in high-Arctic Svalbard (Janssonhaugen) and in the discontinuous permafrost regions of Scandinavia (Juvvasshøe) indicate ground temperatures during 2020 were the highest measured since the late 1990s. The highest warming rate is observed on Svalbard at the Janssonhaugen site (Table 5.2), where cold permafrost has warmed by 0.7°C per decade since 1998, similar to the higher latitude sites in other regions. Lower warming rates are observed in the warm discontinuous permafrost of Scandinavia (e.g., Iskoras), similar to warm permafrost in Russia (e.g., Bolvansky #56) and northwestern North America (Figs. 5.22b,d).

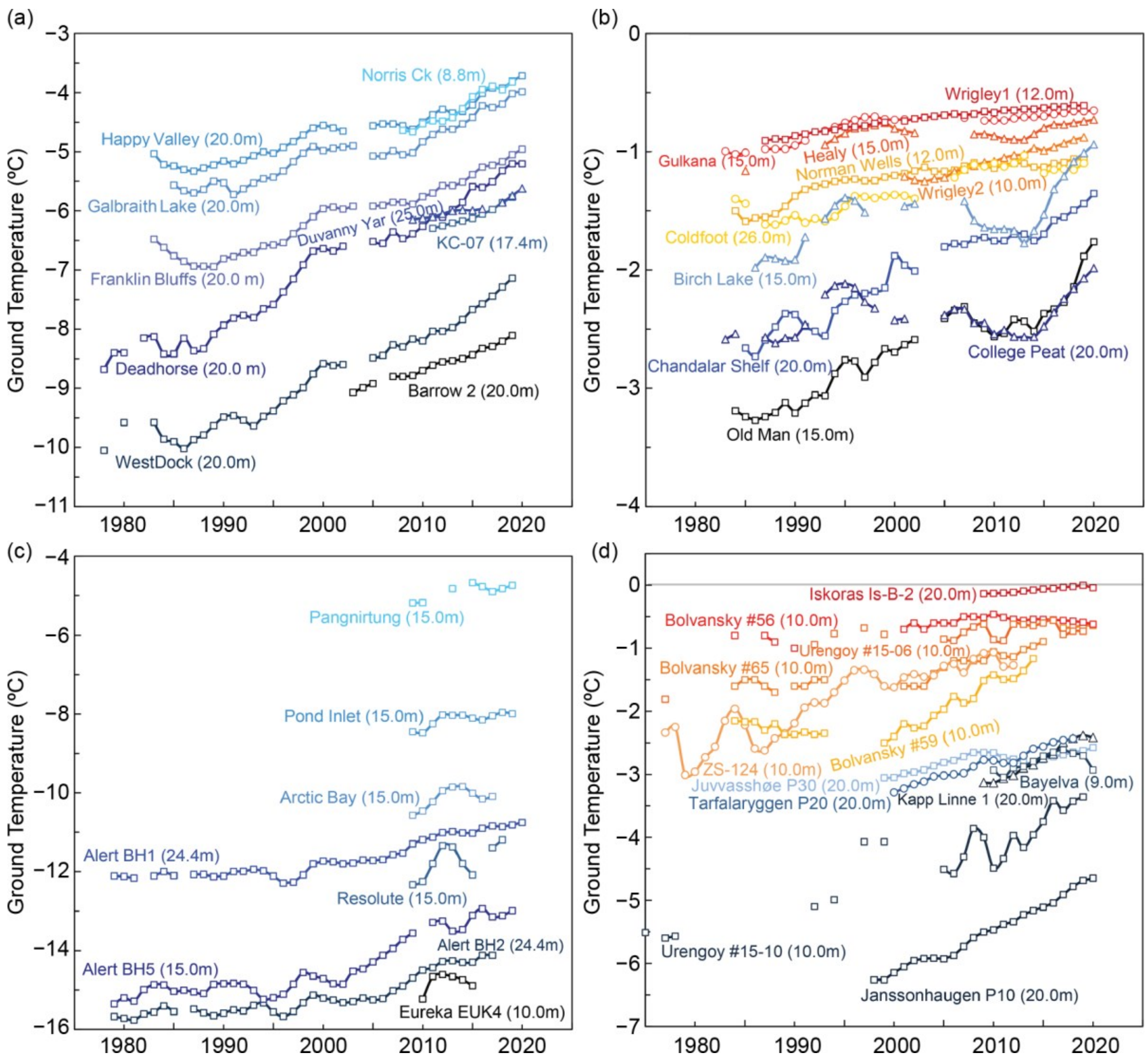

Fig. 5.22. Time series of mean annual ground temperature (°C) at depths of 9–26 m below the surface at selected measurement sites that fall roughly into priority regions of the Adaptation Actions for a Changing Arctic Project (see Romanovsky et al. 2017): (a) cold continuous permafrost of northwestern North America and northeastern East Siberia (Beaufort–Chukchi region); (b) discontinuous permafrost in Alaska and northwestern Canada; (c) cold continuous permafrost of eastern and High Arctic Canada (Baffin Davis Strait); (d) continuous to discontinuous permafrost in Scandinavia, Svalbard, and Russia/Siberia (Barents region). Temperatures are measured at or near the depth of zero annual amplitude where the seasonal variations of ground temperature are less than 0.1°C. Note differences in *y*-axis value range. Borehole locations are shown in Fig. 5.21. Data are updated from Christiansen et al. 2010; Romanovksy et al. 2020; Smith et al. 2019; Ednie and Smith 2015; Boike et al. 2018.

Table 5.2. Rate of change in mean annual ground temperature (°C decade^{-1}) for permafrost monitoring sites shown in Fig. 5.21. For sites where measurements began prior to 2000, the rate of change for the entire available record and the period after 2000 are provided. The periods of record are shown in parenthesis below the rates of change. The names of the stations with record high temperatures in 2020 are shown in red. * denotes sites not reporting in 2020.

Subregions	Sites	Entire Record	Since 2000
Beaufort-Chukchi Region			
North of East Siberia	Duvany Yar (DY)	NA	+0.44 (2009–20)
Alaskan Arctic plain	West Dock (WD)*, Deadhorse (De), Franklin Bluffs (FB), Barrow (Ba)*	+0.40 to +0.81 (1978– 2020)	+0.49 to +0.74 (2000–20)
Northern foothills of the Brooks Range, Alaska	Happy Valley (HV), Galbraith Lake (GL)	+0.35 to +0.44 (1983–2020)	+0.44 to +0.48 (2000–20)
Northern Mackenzie Valley	Norris Ck (No)*, KC-07(KC)*	NA	+0.6 to +0.8 (2008–19)
Discontinuous Permafrost Alaska and NW Canada			
Southern foothills of the Brooks Range, Alaska	Coldfoot (Co)*, Chandalar Shelf (CS), Old Man (OM)	+0.08 to +0.39 (1983–2020)	+0.14 to +0.41 (2000–20)
Interior Alaska	College Peat (CP), Birch Lake (BL), Gulkana (Gu), Healy (He)	+0.09 to +0.30 (1983–2020)	+0.04 to +0.26 (2000–20)
Central Mackenzie Valley	Norman Wells (NW)*, Wrigley (Wr)*	Up to +0.1 (1984–2019)	<+0.1 to +0.2 (2000–19)
Baffin Davis Strait Region			
Baffin Island	Pangnirtung (Pa)*, Pond Inlet (PI)*	NA	+0.4 (2009–19)
High Canadian Arctic	Resolute (Re)*	NA	+0.7 (2009–18)
High Canadian Arctic	Alert (Al) @15m* Alert (Al) @24m	+0.6 +0.4 (1979 – 2020)	+1.1 +0.6 (2000–20)
Barents Region			
North of West Siberia	Urengoy 15-06* and 15-08 (Ur)*	+0.20 to +0.48 (1974–2019)	+0.08 to +0.77 (2005–19)
Russian European North	Bolvansky 56, and 65 (Bo)	+0.05 to +0.26 (1984–2020)	+0.04 to +0.48 (2001–20)
Svalbard	Janssonhaugen (Ja), Bayelva (Bay), Kapp Linne 1 (KL)	+0.7 (1998–2020)	+0.6 to +0.8 (2000–20)
Northern Scandinavia	Tarfalarggen (Ta), Iskoras Is-B-2 (Is)	NA	+0.1 to +0.5 (2000–20)
Southern Norway	Juvvasshøe (Ju)	+0.2 (1999–2020)	+0.2 (2000–20)

2) Active layer thickness

With the exception of the Mackenzie Valley in northwest Canada (at which thaw tubes are used), active layer data reported here were measured by mechanical probing across grids varying from 1 ha to 1 km^2 in size and representative of regional landscapes (Shiklomanov et al. 2012). Increases in ALT are observed over the period of record in some regions but for other regions trends are less evident.

The average ALT (0.46 m) for 12 North Slope of Alaska sites reporting in 2020 was 0.015 m below the 2003–12 mean for the same 12 sites and 0.06 m lower than in 2019 (Fig. 5.23). Observers from local communities were able to make measurements so that some 2020 ALT data were collected. Interior Alaska continues to exhibit pronounced ALT increases over the last 25 years, with a new record average of 0.92 m in 2020.

Sites in Svalbard displayed similar ALT values to the two previous years, values that were approximately 0.13 m above the 2003–12 mean (Fig. 5.23). ALT for Greenland in 2020 was similar to that in 2019, 0.08 m above the 2003–12 mean (Strand et al. 2020).

Sites in West and East Siberia reported increased ALT in 2020, continuing the general trend, with the average ALT (1.46 m) for West Siberia being a new record maximum for the observation period (Fig. 5.23). Significant ALT reduction was reported in 2020 for sites in the Russian European North and Chukotka, but these values are based on fewer sites and may not be representative of regional trends previously reported (Abramov et al. 2019; Vasiliev et al. 2020).

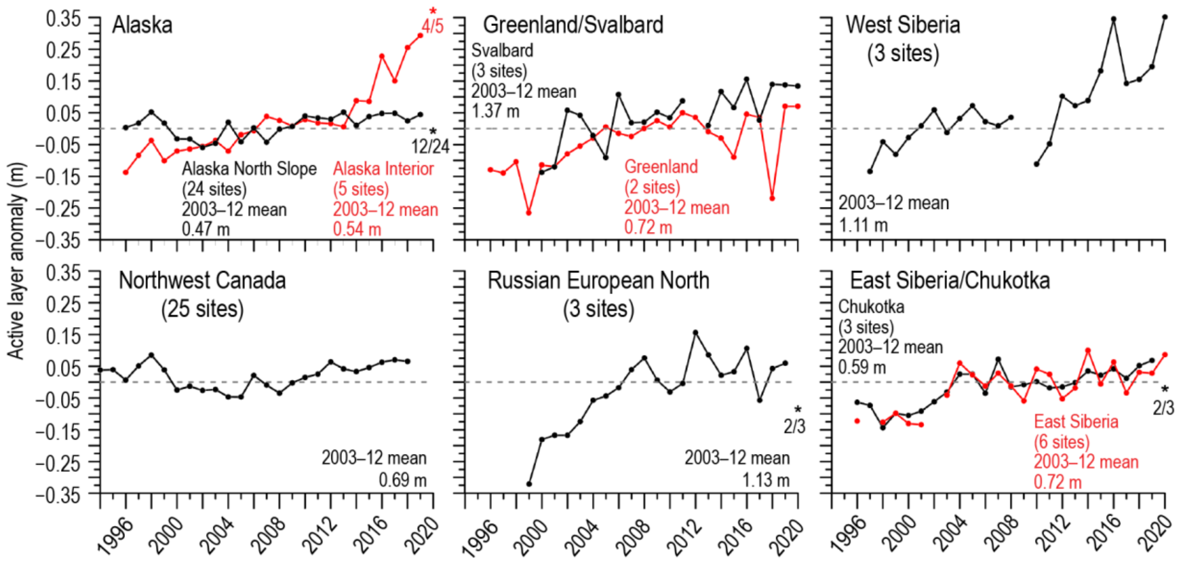

Fig. 5.23. Long-term active layer thickness anomalies in six different Arctic regions as observed by the Circumpolar Active Layer Monitoring (CALM) program. The data are shown as annual anomalies (m) relative to the mean value for the reference period 2003–12. Positive and negative anomaly values indicate the active layer is thicker or thinner than the 10-year mean values, respectively. The number of sites varies by region (numbers provided on figure), because only sites with >20 years of continuous thaw depth observations from the end of the thaw season were included. Asterisks on the figure represent 2020 data, as observations from fewer sites (number provided beside asterisks) were possible due to pandemic-related restrictions. Site-specific data are available at www2.gwu.edu/~calm/.

i. Tundra greenness—G. V. Frost, M. J. Macander, U. S. Bhatt, H. E. Epstein, L. T. Berner, J. W. Bjerke, B. C. Forbes, S. J. Goetz, M. J. Lara, T. Park, G. K. Phoenix, M. K. Raynolds, H. Tømmervik, and D. A. Walker

Occupying Earth's northernmost lands, the Arctic tundra biome is a focal point of global environmental change because vegetation and underlying permafrost soils are strongly influenced by warming air temperatures and interactions with sea ice loss in the adjacent Arctic Ocean (Lawrence et al. 2008; Bhatt et al. 2010; Serreze and Barry 2011; sections 5b–d). One of the most striking consequences of the Arctic's warming climate has been an increase in the productivity ("greenness") of tundra vegetation, which is largely governed by summer temperature (Berner et al. 2020; Bjorkman et al. 2020). Tundra greenness has been monitored by Earth-observing satellites since 1982 and a growing constellation of spaceborne sensors provide increasingly detailed observations of Arctic ecosystems.

The spaceborne record of global vegetation productivity began in late 1981 using the Advanced Very High Resolution Radiometer (AVHRR), a sensor that collects daily observations and continues to operate onboard polar-orbiting satellites today. The long-term dataset reported here is the Global Inventory Modeling and Mapping Studies 3g V1.2 dataset (GIMMS-3g+), which is based on corrected and calibrated AVHRR data with a spatial resolution of about 8 km (Pinzon and Tucker 2014). At the time of this writing, however, processed GIMMS-3g+ data are available only through the 2019 growing season. Therefore, we also report observations from the Moderate Resolution

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a. Overview

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b. Surface air temperature

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d. Sea ice

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e. Greenland ice sheet

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g. River discharge

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i. Tundra greenness

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Chapter 5 – Acronyms

ALT	active layer thickness
AON	Arctic Observing Network
ARC	Arctic Report Card
AVHRR	Advanced Very High Resolution radiometer
AWS	automated weather stations
BUI	Buildup Index
CALM	Circumpolar Active Layer Monitoring
CFFDRS	Canadian Forest Fire Danger Rating System
CMC	Canadian Meteorological Centre
DMI	Danish Meteorological Institute
DU	Dobson units
GIMMS-3g+	Global Inventory Modeling and Mapping Studies 3g V1.2
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	GRACE Follow-On
HNL	high northern latitudes
ICESat-2	Ice, Cloud, and land Elevation 2
IMS	Interactive Multisensor Snow and Ice Mapping System
MAR	Modèle Atmosphérique Régional
MaxNDVI	maximum NDVI
MCD43A4	Nadir Bidirectional Reflectance Distribution Function Adjusted Reflectance
MERRA-2	Modern-Era Retrospective Analysis for Research and Applications version 2
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectroradiometer
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
NDVI	Normalized Difference Vegetation Index
NH	Northern Hemisphere
NSIDC	National Snow and Ice Data Center
OISSTv2	Optimum Interpolation Sea Surface Temperature version 2
OMI	Ozone Monitoring Instrument
OSI SAF CCI	Ocean and Sea Ice Satellite Application Facility Climate Change Initiative
PM	Passive Microwave
PROMICE	Programme for Monitoring of the Greenland Ice Sheet
PSCs	polar stratospheric clouds
SAT	surface air temperature
SCD	snow cover duration
SCE	snow cover extent
SLP	sea-level pressure
SMB	surface mass balance
SMOS	Soil Moisture Ocean Salinity
SPEI	Standardized Precipitation-Evapotranspiration Index
SSMIS	Special Sensor Microwave Imager/Sounder

SSTs	sea surface temperatures
SWE	snow water equivalent
TOC	total ozone column
UV	ultraviolet
UVI	ultraviolet index
VTA	value tree assessment

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