frontiers

Supplementary Material

The Changing Face of the Arctic: Four Decades of Greening and Implications for Tundra Ecosystems

1 Time series construction

1.1 MODIS time series construction

1. For each year, any missing data was filled with the long-term median value (there don't tend to be many missing values).

2 For each month, pixels with SummaryQA ≥ 3 were masked (indicating cloudy or otherwise compromised observations), and then the long-term median and the count of years with data were computed. Pixels were excluded if they had data for <80% of years.

3 The long-term normal was then used to mask out annual data in pixels that didn't have data in ≥ 80% of years, and fill in any missing data values for remaining pixels. Finally, NDVI values < 0.05 were set to zero, following the convention used with GIMMS-3G+.

4 TI-NDVI was then calculated as the annual sum of monthly NDVI values (May-September only). The annual sum was then multiplied by 2 to maintain a comparable scale to the GIMMS-3G+ TI-NDVI, which is calculated from bimonthly composites.

5 For TI-NDVI, the Aqua and Terra products were processed separately, but were then aggregated to a single mean value (2003–2023; for 2000–2002 the data were Terra only).

6 The significance filter removes a lot of the MODIS TI-NDVI trends.

1.2 Landsat time series construction

1 ~100,000 points were randomly selected from lands within the domain of the Circumpolar Arctic Vegetation Map.

2 Growing season Landsat 4/5/7/8/9 observations were extracted at the sample points following the methods of Berner et al. (2020, 2023). In brief, a set of cross-calibration coefficients was developed to normalize NDVI from all sensors to match Landsat 7. A phenology adjustment was also applied to estimate MaxNDVI from all the QA-filtered observations in a growing season. The end result was a single estimate of Landsat MaxNDVI for each year when at least one observation was available.

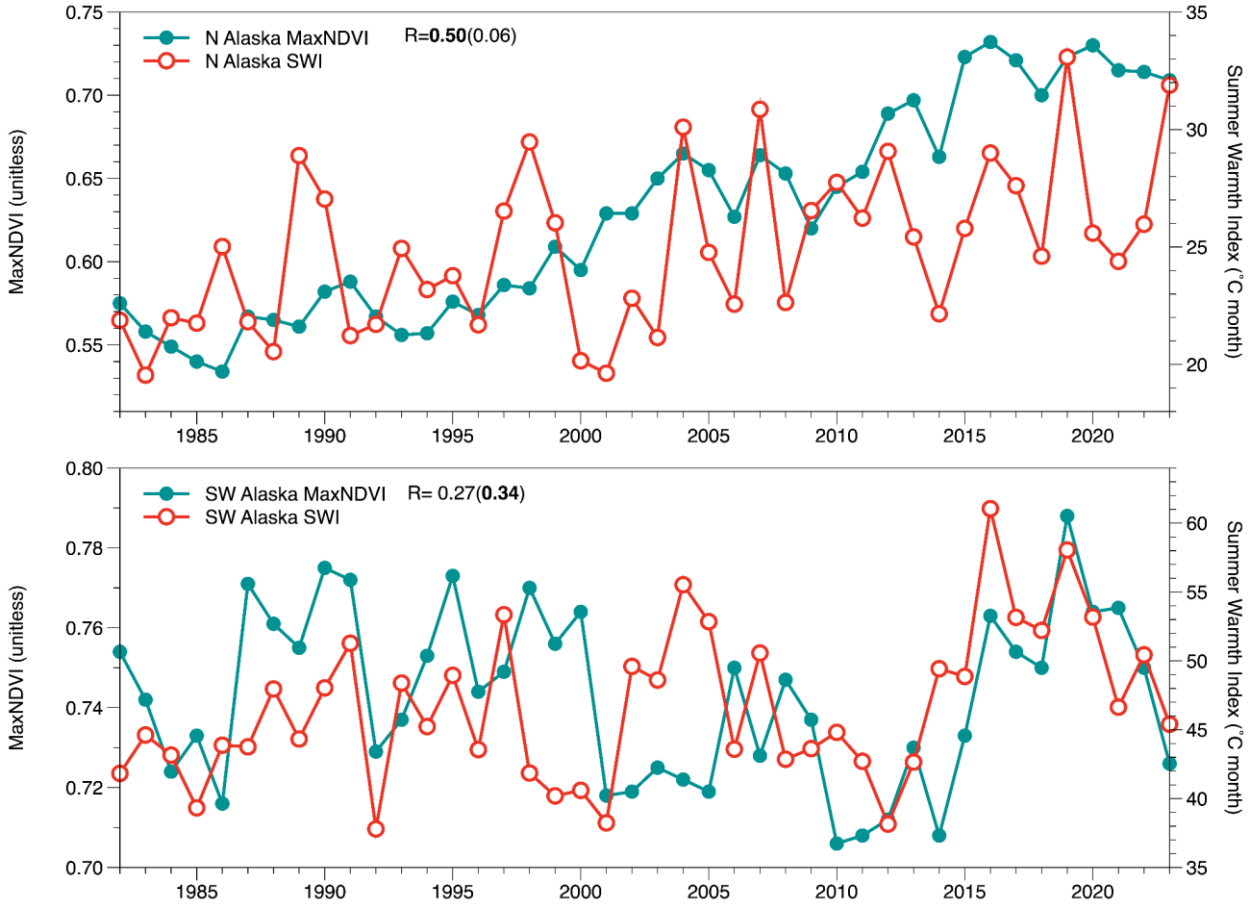
3 Linear trends were calculated and a statistical significance filter of ($p < 0.1$) was applied following the same approach used for other datasets.

4 For circumpolar trend maps of Landsat MaxNDVI, points with too few data were excluded. The criteria for rejection were:

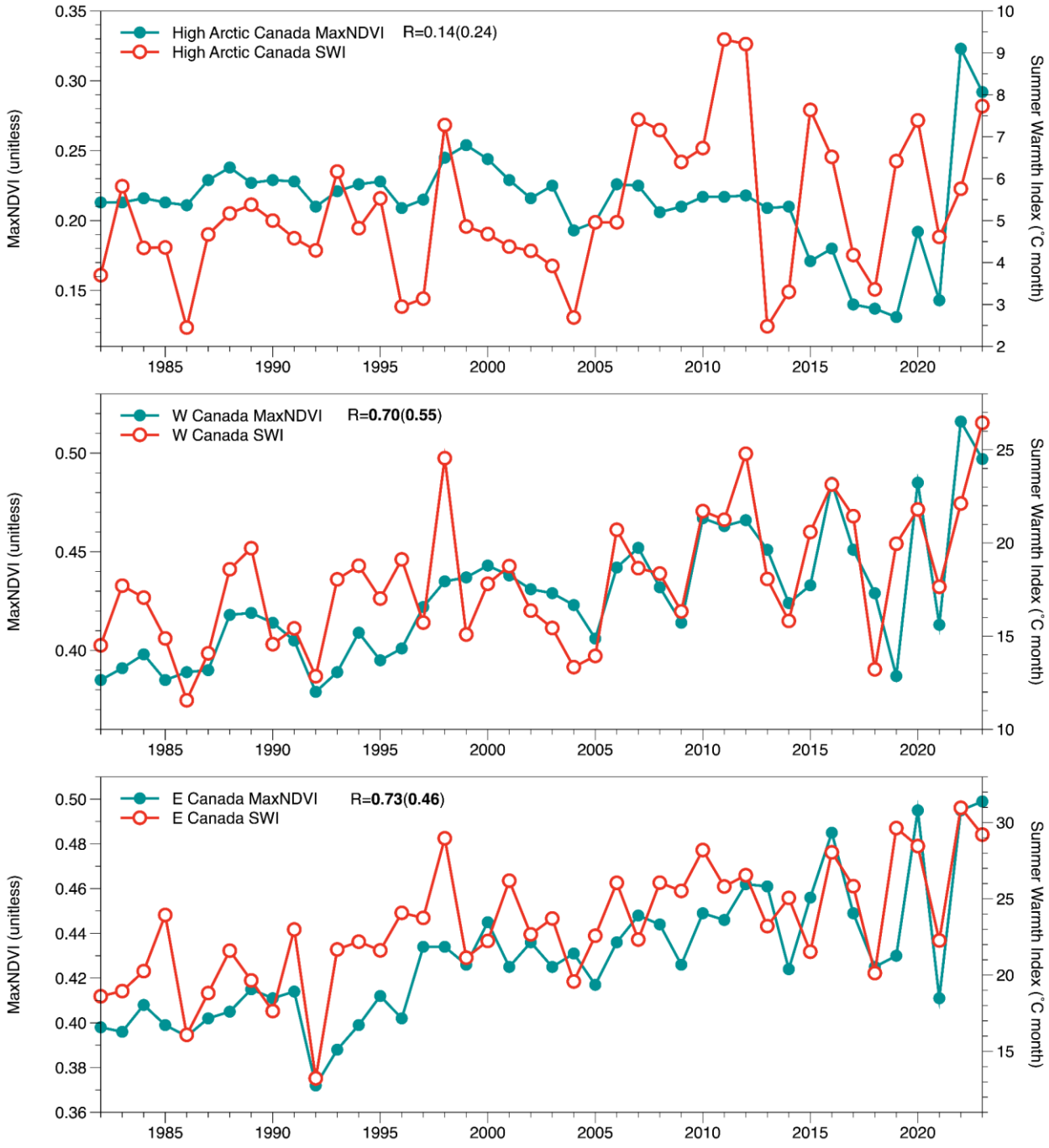
4.1 first.yr > 1989 (for 1984–2023 trend) or 2001 (for 2000–2023 trend)
4.2 last.yr < 2022, or
4.3 proportion of years with observations < 2/3 of the years in the time-series.

5 Landsat sample points were then aggregated to 20 km grid cells in the Lambert polar projection (the same used for MODIS) and the mean trend value was calculated for each grid cell.

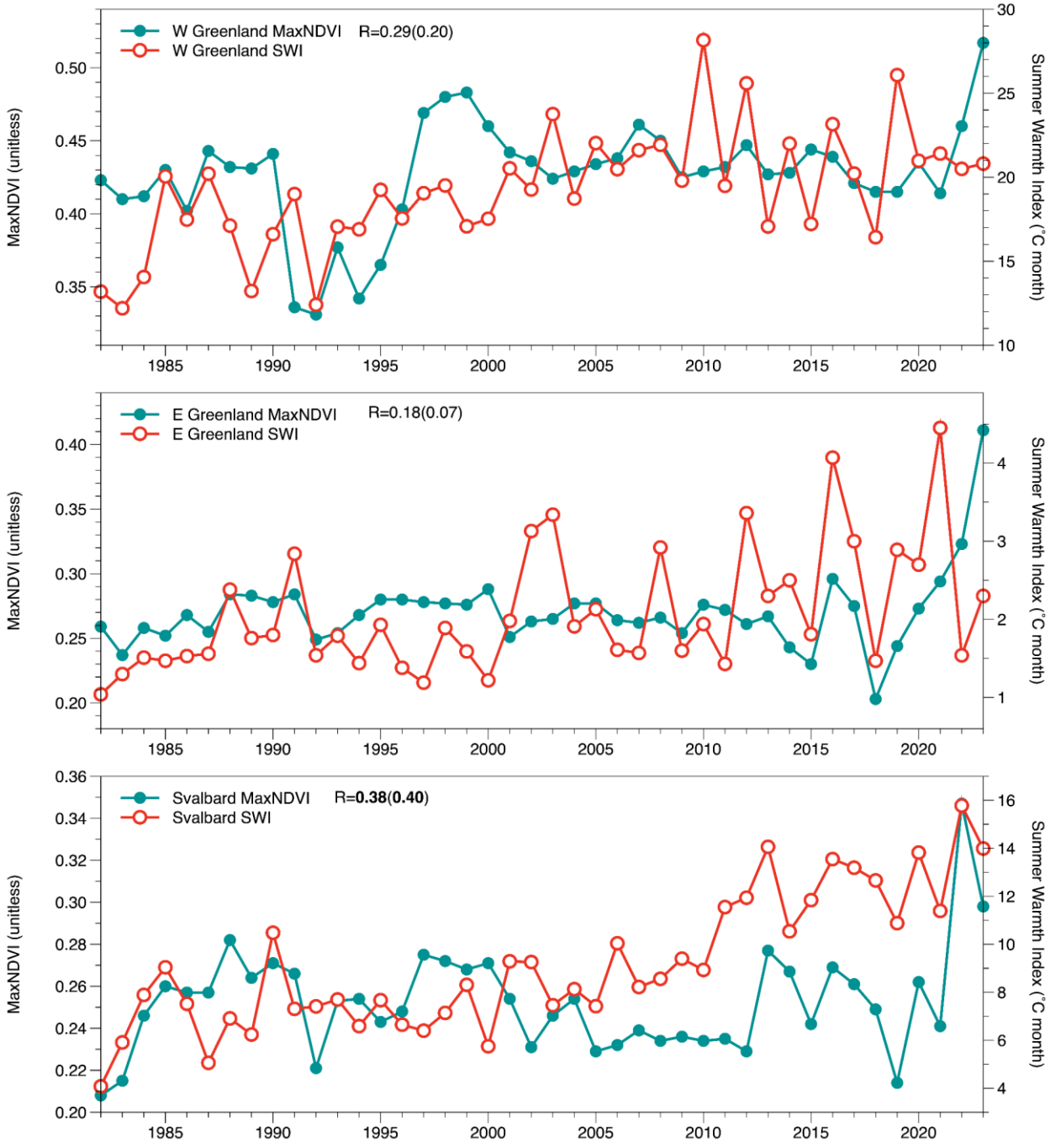
2 Regional time-series of MaxNDVI and Summer Warmth Index



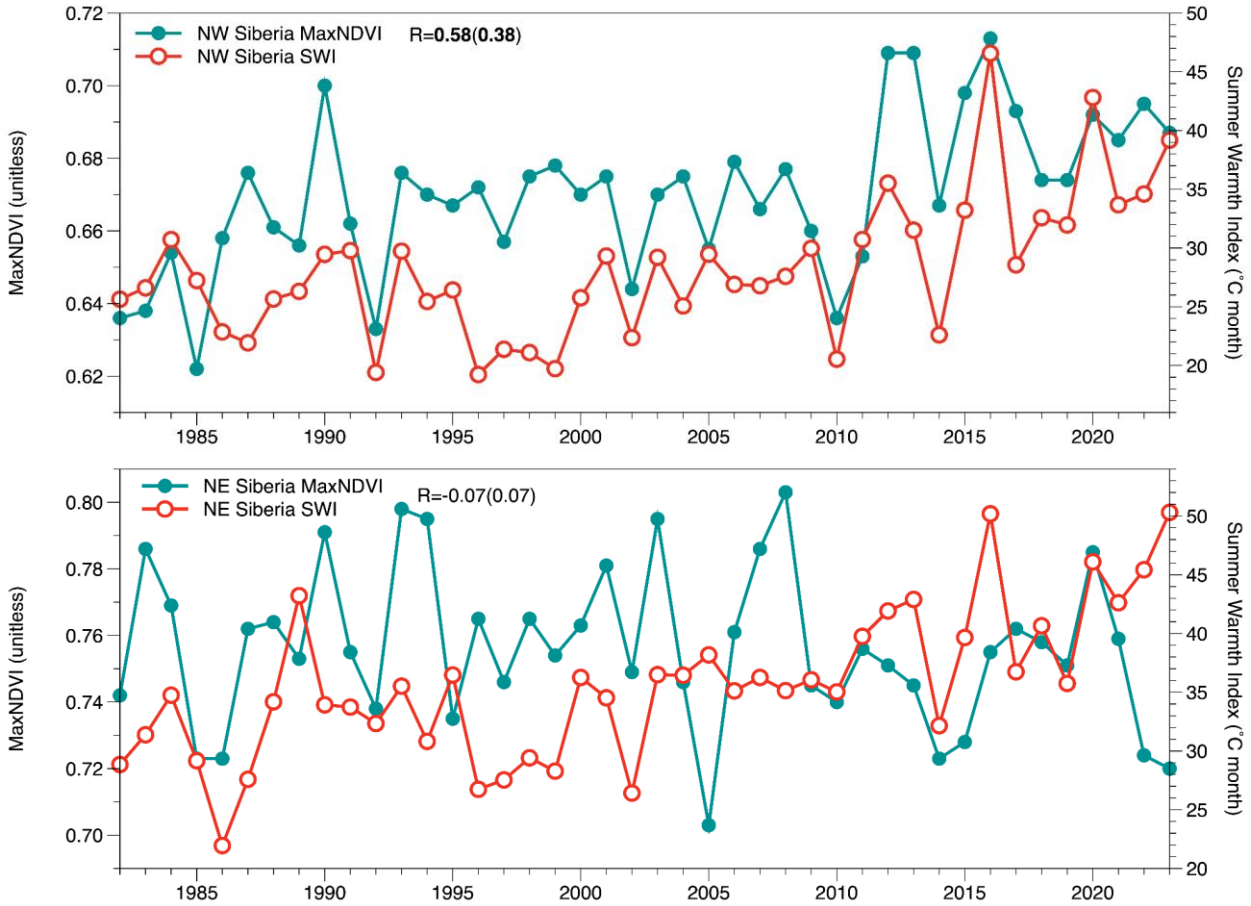
Supplementary Figure 1. Time-series of average GIMMS-3g+ MaxNDVI and Summer Warmth Index over northern (top) and southwestern (bottom) Arctic Alaska. Pearson's correlation coefficients are given for raw and linearly detrended values (in parenthesis); boldface indicates Student's T-test significance ≥ 95%.



Supplementary Figure 2. Time-series of average GIMMS-3g+ MaxNDVI and Summer Warmth Index over the Canadian High Arctic (top), and the western (middle) and eastern (bottom) Canadian Low Arctic. Pearson's correlation coefficients are given for raw and linearly detrended values (in parenthesis); boldface indicates Student's T-test significance ≥ 95%.



Supplementary Figure 3. Time-series of average GIMMS-3g+ MaxNDVI and Summer Warmth Index over western (top) and eastern (middle) Greenland, and Svalbard (bottom). Pearson's correlation coefficients are given for raw and linearly detrended values (in parenthesis); boldface indicates Student's T-test significance ≥ 95%.



Supplementary Figure 4. Time-series of average GIMMS-3g+ MaxNDVI and Summer Warmth Index over northwestern (top) and northeastern (bottom) Low Arctic Siberia. Pearson's correlation coefficients are given for raw and linearly detrended values (in parenthesis); boldface indicates Student's T-test significance ≥ 95%.