Decadal-to-Annual Scale Trends in Regional Arctic Late-Summer Sea Ice Extent

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Abstract

Significant declines in late summer sea ice extent (SIE) since the late 1970's suggest a future Arctic that will be largely "ice-free" in the late summer. But changes in Arctic SIE are not uniform by region and vary over decadal-to-annual scales. In this study, satellite-derived data products on Arctic SIE from 1979-present were used to investigate decadal-to-annual scale trends in late-summer sea ice extent changes by region to better identify regional "hot-spots" for future change. Results confirm significant decadal-scale negative trends in late-summer SIE for all regions of the Arctic with the largest decreases observed in the Russian Arctic (Chukchi Sea, Kara Sea, East Siberian Sea, and Laptev Sea) and the Beaufort Sea which also contain the majority of total Arctic late-summer SIE. The SIE anomaly in these same regions also shows significant annual-scale variability marked by years with extremely low late-summer SIE followed by "rebound" years that have higher SIE but still follow the overall decadal-scale negative trend. Understanding these regional differences and temporal variability is important because of the impact future changes in sea ice cover could have on Arctic ecosystems and regional climate.

Background, Approach, and Methods

Satellite passive microwave observations show a significant decline in Arctic sea ice cover since 1978. This decline is most pronounced in late-summer at the end of the seasonal melt cycle and varies by region indicating an Arctic in transition from a multi-year sea ice regime to a more spatially-heterogeneous regime dominated by thinner seasonal ice that is largely ice free in the late summer (*Cavalieri and Parkinson, 2012; Stroeve et al., 2007; Onarheim et al., 2018*). Sea ice varies significantly by Arctic sub-region and also vary on interannual-to-multi-decadal scales as a function of natural and anthropogenic forcing and complex Arctic feedbacks (*Kay et al., 2011; Onarheim et al., 2018*). Understanding these regional differences and temporal variability is important because of the impacts future changes in sea ice cover could have on Arctic ecosystems and regional weather and climate (*Honda et al., 2009*). In this study, satellite-derived data products on Arctic sea ice extent (SIE) from 1979-present were used to investigate decadal-to-annual scale trends in SIE changes by region to better identify regional "hot-spots" of future change.

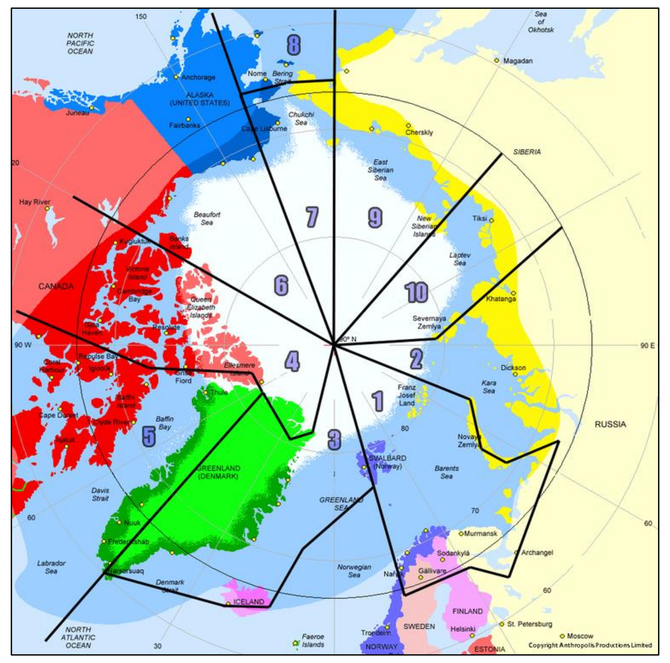

Figure 1. Map of the Arctic separated by geographic regions for sea ice: 1. Barents Sea; 2. Kara Sea; 3. Greenland Sea; 4. Canadian Arctic; 5. Baffin Bay; 6. Beaufort Sea; 7. Chukchi Sea; 8. Bering Sea; 9. East Siberian Sea, and; 10. Laptev Sea from the Arctic Regional Ocean Observing System (Arctic ROOS) website (https://arctic-roos.org/ observations/ sea-ice-variability-in-regions).

***References**: Cavalieri D.J. and Parkinson C.L., 2012, The Cryosphere 6: 881–889; Fetterer F., 2017, Sea Ice Index, Version 3., Daily Arctic Sea Ice Extent (GeoTiff),NSIDC: National Snow and Ice Data Center, ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/north/daily/geotiff/ : accessed 15 April 2020; Honda M., 2009, Geophys. Res. Lett. 36: L08707; Kay J.E. et al., 2011, Geophys. Res. Lett. 38: L15708; Nansen Environmental & Remote Sensing Center, 2019, Arctic ROOS: https://arctic-roos.org/ observations, accessed 15 April 2020; Onarheim I.H. et al., 2018, Journal of Climate 31: 4917-4932; Stroeve J.C., 2012, Climatic Change 110:1005–1027.*

The cumulative area of polar grid cells in the Northern Hemisphere that have at least 15% sea ice concentration, or SIE, was used as a measurement of sea ice cover. This study utilized Sea Ice Index data products in the form of GeoTiff images (25 km x 25 km grid) of daily SIE for the sea ice minimum from 1980-2019 downloaded from the U.S. National Snow and Ice Data Center (*NSIDC; Fetterer et al., 2012*). GeoTiffs of SIE were used to create raster images in ESRI ArcGIS Pro that represent an estimate of the spatial median SIE (grids areas with ice over 50% of the total years) for 1981-2010 and for the decades since 1980: 1980-1989; 1990-1999; 2000-2009; and 2010-2019. Mean September SIE (km^2) for the total Arctic and for 10 defined sub-regions of the Arctic (**Fig. 1**) were downloaded from the Nansen Environmental & Remote Sensing Center, Arctic ROOS website. MATLAB r2017a and MS Excel were used to process these data and to estimate the 1981-2010 mean late-summer SIE for the total Arctic and each sub-region of the Arctic (**Fig. 1**), SIE anomalies (from 1981-2010 mean), and to estimate trends in late-summer SIE using a simple linear regression model fit. All SIE data were derived from satellite passive microwave-derived data from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR), the U.S. Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I), and Special Sensor Microwave Imager/Sounder (SSMIS).

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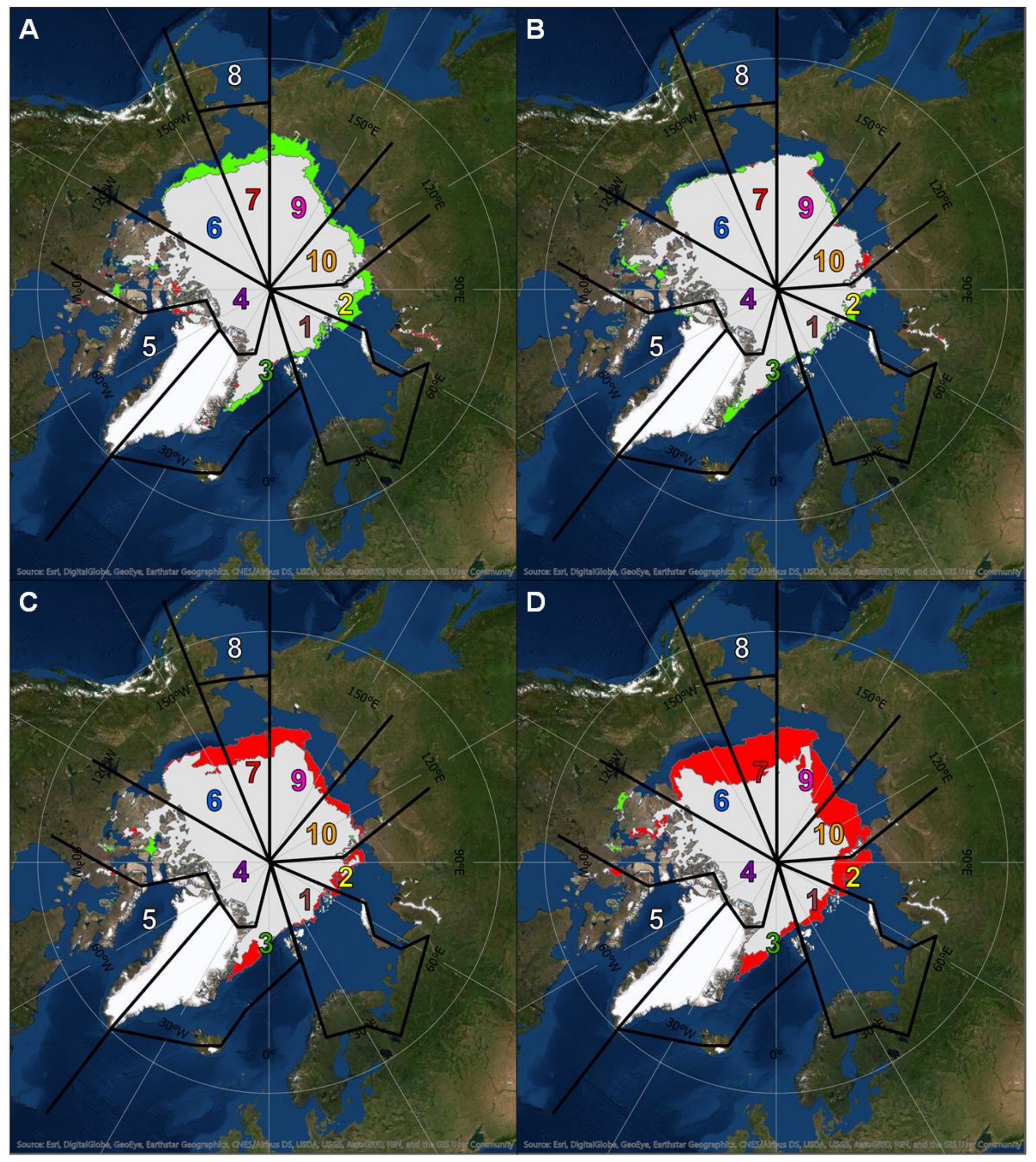

Figure 2. Map of the Arctic separated by geographic regions (**Fig. 1**) showing areas of with a greater minimum SIE (green) and a lower minimum SIE (red) as compared to the 1981-2010 median SIE for (**A**) 1980-1989; (**B**) 1990-1999; (**C**) 2000-2009, and; (**D**) 2010-2019.

Results and Discussion

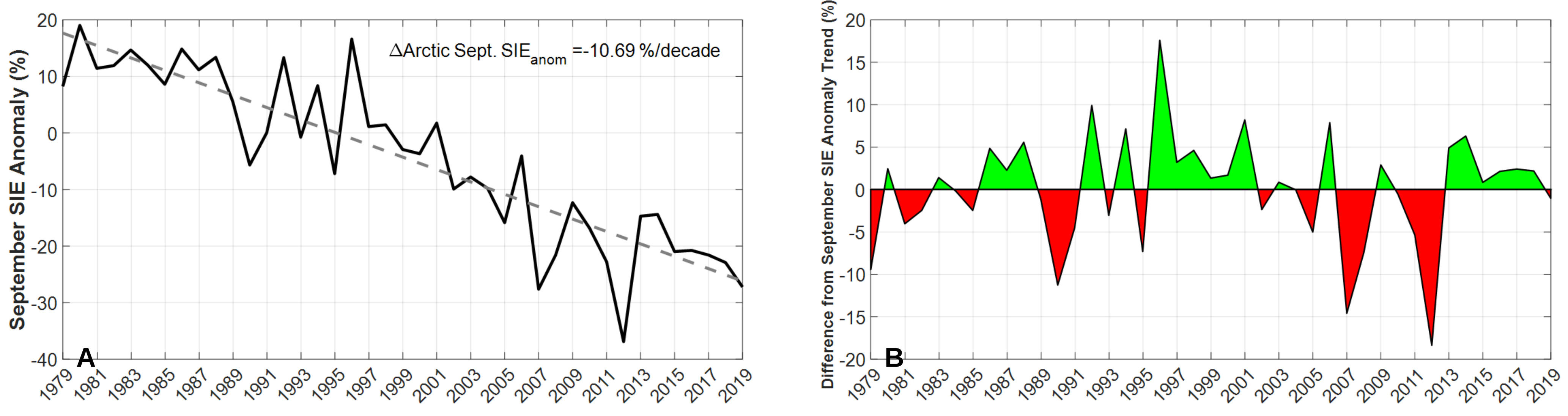

Figure 3. (**A**) Linear regression model fit to the mean September SIE anomaly from 1979-2019 referenced to the 1981-2010 mean September SIE expressed as a percent of the 1981-2010 mean. The fit shows the total Arctic mean September SIE declining at a rate of -10.69% per decade. (**B**) Difference in the mean September SIE anomaly from 1979-2019 from the mean September SIE anomaly predicted by the linear regression model fit.

Figure 2 shows a clear decline in late-summer Arctic SIE as compared to the 1981-2010 mean between the 1980s (**Fig. 2A**), the 1990s (**Fig. 2B**), the 2000s (**Fig. 2C**), and the 2010s (**Fig. 2D**). Compared to the 1981-2010 mean, late-summer SIE was higher in the 1980s in all Arctic sub-regions except for small portions of Baffin Bay and the Canadian Arctic (regions 4 & 5; **Fig. 2A**). And in the 2010s, late-summer SIE was significant lower in all sub-regions with the exception of some parts of the Canadian Arctic (region 4). The largest decadal-scale declines in late-summer SIE were in the Chukchi Sea, Kara Sea, East Siberian Sea, and Laptev Sea, Beaufort Sea (regions 7, 2, 9, 10, and 6, respectively; **Fig. 2D**). Overall, the total Arctic late-summer SIE has been decreasing at a rate of ~ -10.7% per decade from 1979-2019 (**Fig. 3A**) but the decreasing trend has not been linear, with some anomalously low SIE years (i.e.. 2007 and 2012) and some anomalously high years (i.e.. 1992 and 1996) (**Fig. 3B**). Similarly, decadal-scale declines in late-summer SIE exist in all Arctic sub-regions with the highest rates of decline in the Russian Arctic and the Beaufort Sea (**Fig. 4A**). But as with the trend in total Arctic late-summer SIE, the declining trend has not been linear in Arctic sub-regions (**Figs. 4A.1-8**) with the exception of maybe the Canadian Arctic (**Fig. 4A.4**) where late summer SIE has been decreasing consistently at only ~ 1.9%/decade. The overall declines estimated in this study are consistent with those estimated by others (*Cavalieri and Parkinson, 2012; Onarheim et al., 2018*) and the quasi-cyclic nature of the observed variation between anomalously low late-summer SIE years and anomalously high late-summer SIE years is also an area of ongoing research by others (*Kay et al., 2011*).

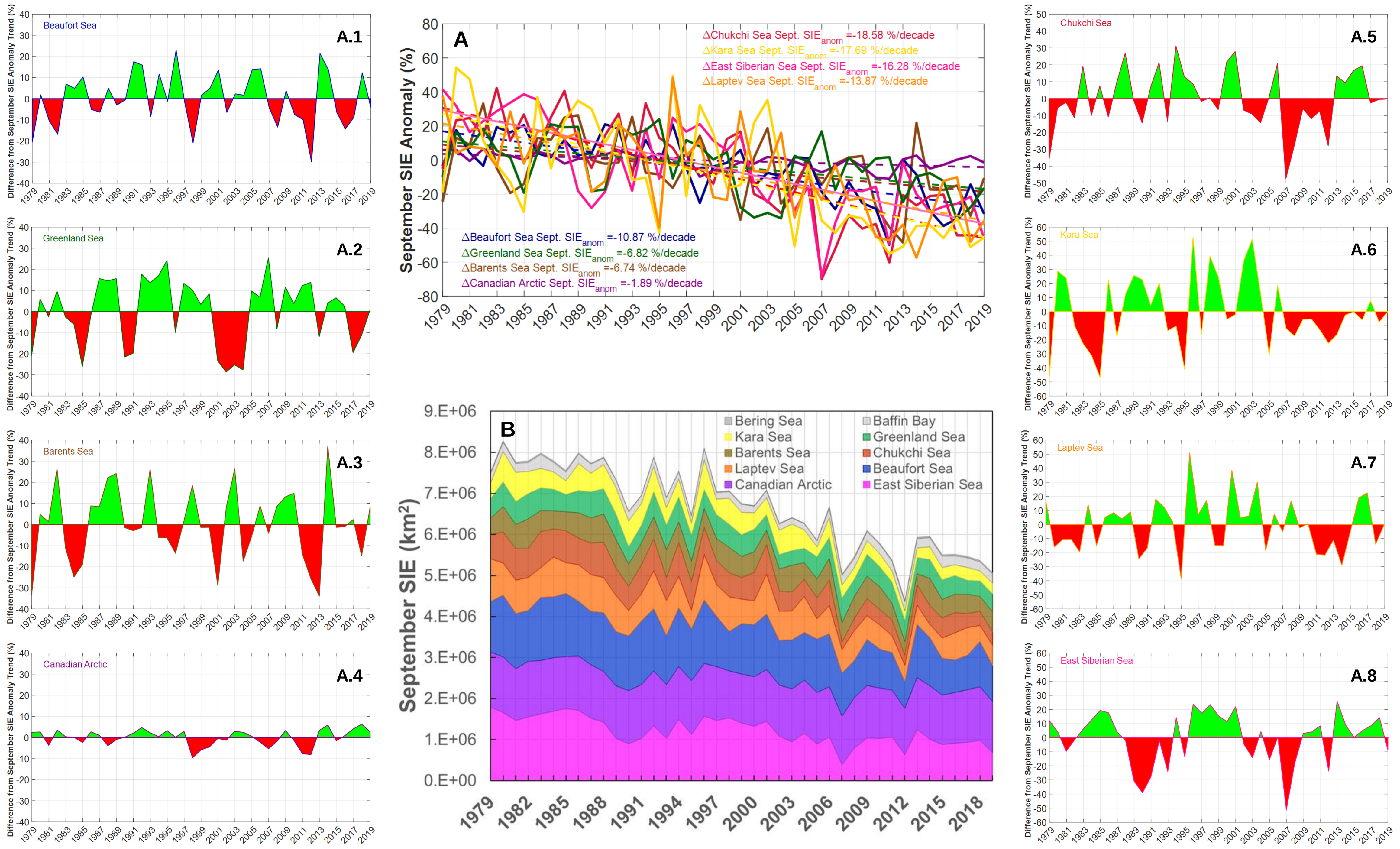

Figure 4. (**A**) Linear regression model fit to regional (**Fig.1**) mean September SIE anomalies from 1979-2019 referenced to the regional 1981-2010 mean September SIE expressed as a percent of the 1981-2010 mean (**Fig. 1**). Sub-figures (**A1-8**) showing the difference in regional mean September SIE anomalies from 1979-2019 from the mean September SIE anomaly predicted by the linear regression model fit for each region. Note: Baffin Bay and the Bering Sea (Region 5 and 8) are not shown due to the low expected SIE in late summer. (**B**) The total Arctic mean September SIE expressed in (km^2) from 1979-2019 broken down by the contribution for each Arctic sub-region.

As previously stated, late-summer SIE (km^2) from 1979-2019 in each Arctic sub-region has a downward trend but the annual-to-decadal scale contribution of each Arctic sub-region to the overall decline in late summer SIE for the total Arctic varies (**Fig. 4B**). This is especially true for the sub-regions of the Russian Arctic and Beaufort Sea which have the largest proportional contribution to late-summer Arctic SIE and also show the largest rates of decline (**Fig. 4A**; *Onarheim et al., 2018*). It is important to better understand these temporal and regional differences in late-summer Arctic SIE decline because of the important role sea ice plays in Arctic ecosystems and as a feedback for regional weather and climate (*Honda et al., 2009*).

Conclusions

- ***Results show significant decadal-scale decline in late-summer SIE from 1979-2019 for all sub-regions of the Arctic with the largest decreases observed in "hot-spots" in the Russian Arctic and the Beaufort Sea which also contain the majority of total Arctic late-summer SIE. The SIE anomaly in these regions shows significant, and possibly quasi-periodic, annual-scale variability but still follows the overall decadal-scale negative trend.***
- ***Future research should include studies of trends in seasonal SIE, sea ice concentration, and melt season and investigate how short-to-long term trends might impact the Arctic environment and regional security in the future.***