Erratum for Arctic Ocean Primary Productivity: The Response of Marine Algae to Climate Warming and Sea Ice Decline

K. E. Frey[1], J. C. Comiso[2], L. W. Cooper[3], J. M. Grebmeier[3], and L. V. Stock[2]

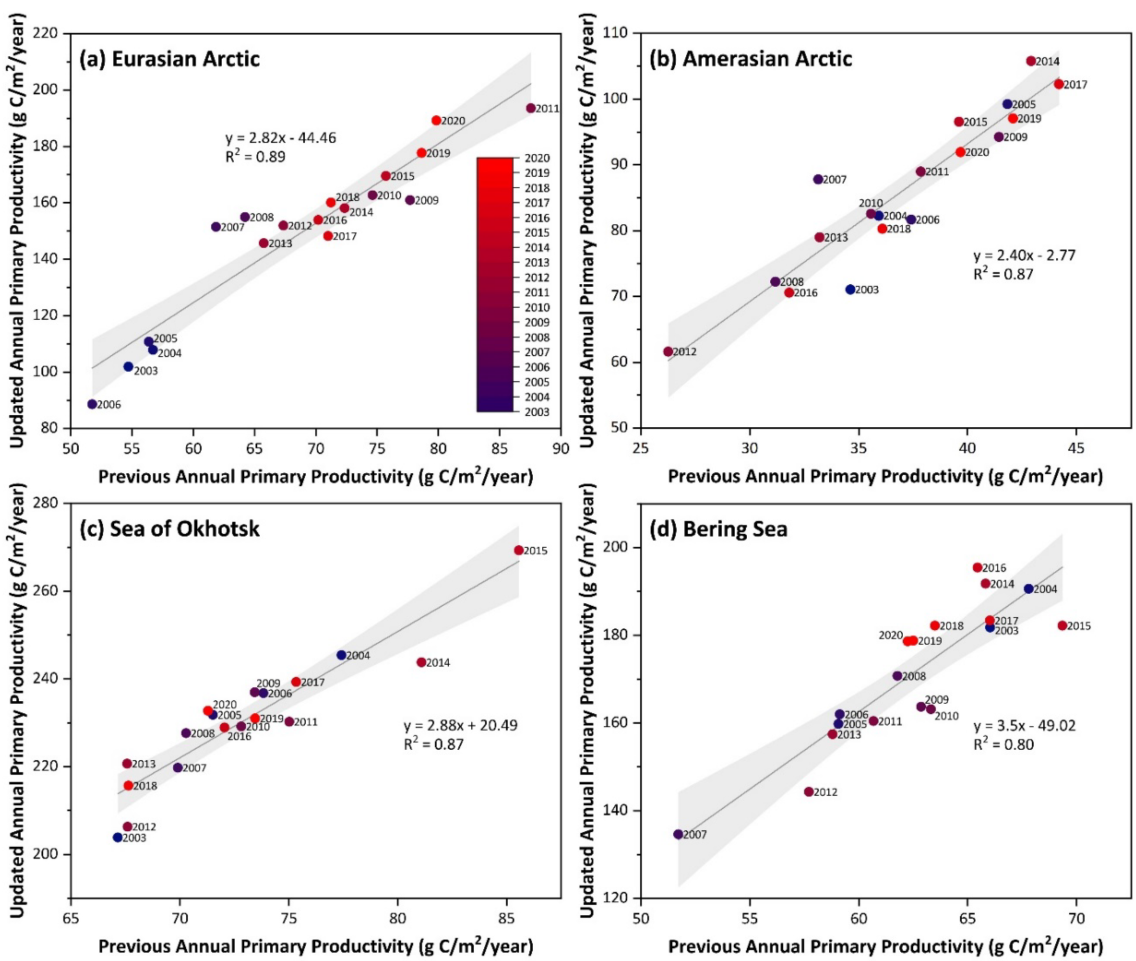
[1]Graduate School of Geography, Clark University, Worcester, MA, USA
[2]Cryospheric Sciences Laboratory, Goddard Space Flight Center, NASA, Greenbelt, MD, USA
[3]Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD, USA

Overview

The primary productivity data used in recent Arctic Report Card essays on Arctic Ocean primary productivity (Frey et al. 2015, 2016, 2017, 2018, 2019, 2020, 2021) have been based on a global algorithm (Behrenfeld and Falkowski 1997). This algorithm makes use of input data that include sea surface temperatures (SST) and chlorophyll-*a* concentrations. Several studies focused on both the Arctic and Antarctic regions were previously published using this algorithm (e.g., Smith and Comiso 2008; Comiso 2010), incorporating SST data derived at NASA Goddard Space Flight Center (GSFC) from Advanced Very High Resolution Radiometer (AVHRR) data and chlorophyll-*a* data from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) ocean color data (also derived at GSFC). For consistency, this same algorithm has been used (up to the present) for the Arctic Report Card essays, although there have been other algorithms that have been developed since 1997 (e.g., Lewis et al. 2020). However, when primary productivity data were initially needed for the Arctic Report Card in 2015, the primary productivity dataset maintained at GSFC shifted to utilize a different SST dataset than those used in previous publications (prior to 2015). In particular, the NOAA/Reynolds Optimum Interpolation SST (OISST) dataset started to be used for convenience since NOAA had begun to incorporate AVHRR data to supplement the in-situ SST measurements. The switch was justified because, with the addition of these AVHRR data, the NOAA OISST product became much more consistent with the GSFC SST product that relied more on satellite data in the polar regions where there is a paucity of in-situ measurements. However, through the process of shifting SST datasets, this led to an inadvertent programming error that is now being reported in this erratum. In the previously revised version of the programming code, SST was set to zero and, in the process, estimates of primary productivity became erroneous. The error was not immediately noticed since the incorrect values appeared realistic and it was not until 2021 that the error was discovered. Since the updated primary productivity values are significantly different from the previous values, this erratum was deemed necessary to inform the public that the values and trends for primary productivity were erroneous in Frey et al. (2015, 2016, 2017, 2018, 2019, 2020). No other variables reported in these essays (chlorophyll-*a* concentrations and sea ice concentrations) are erroneous and they stand as reported. The primary productivity values and trends reported in Arctic Report Card 2021 (Frey et al. 2021) are correct and reflect values in which SST is appropriately incorporated.

Updated vs. previous dataset comparisons

To assess the overall impact of the updated code that now incorporates SST appropriately, we include analyses that compare primary productivity and trends of primary productivity for our standard nine Arctic regions over the 2003-20 period (Figs. 1 and 2, Table 1). Linear regressions of the updated annual primary productivity values vs. the previous annual primary productivity values show that the updated estimates are all higher than previous estimates. In particular, the updated values range on average from 2.37 to 4.02 times higher than previous estimates (Fig. 1, Table 1), with an average of 2.65 times higher for all nine regions (Fig. 1j, Table 1). The smallest differences occur for regions that exhibit cooler annual SST values (Greenland Sea and Baffin/Labrador Sea; new values average 2.37 times higher; Fig. 1f and 1h), whereas the greatest differences occur for regions that exhibit warmer annual SST values (North Atlantic; new values average 4.02 times higher; Fig. 1i). These results are expected because the cooler regions exhibit SSTs more similar to the previous incorrectly designated SSTs (i.e., those incorrectly set at zero). Given the overall higher primary productivity values in the updated dataset, the updated calculated decadal trends in primary productivity over the years 2003-20 are now higher as well (Fig. 2, Table 1). On average, the updated decadal trends are nearly three times higher than previous trends, with the smallest difference for the Hudson Bay (~1.5 times higher) and the largest difference for the Bering Sea (~6 times higher). Overall, the general story of how primary production is changing across the Arctic does not deviate from what was reported in previous Arctic Report Card essays (i.e., long-term increases in primary productivity across all regions of the Arctic).



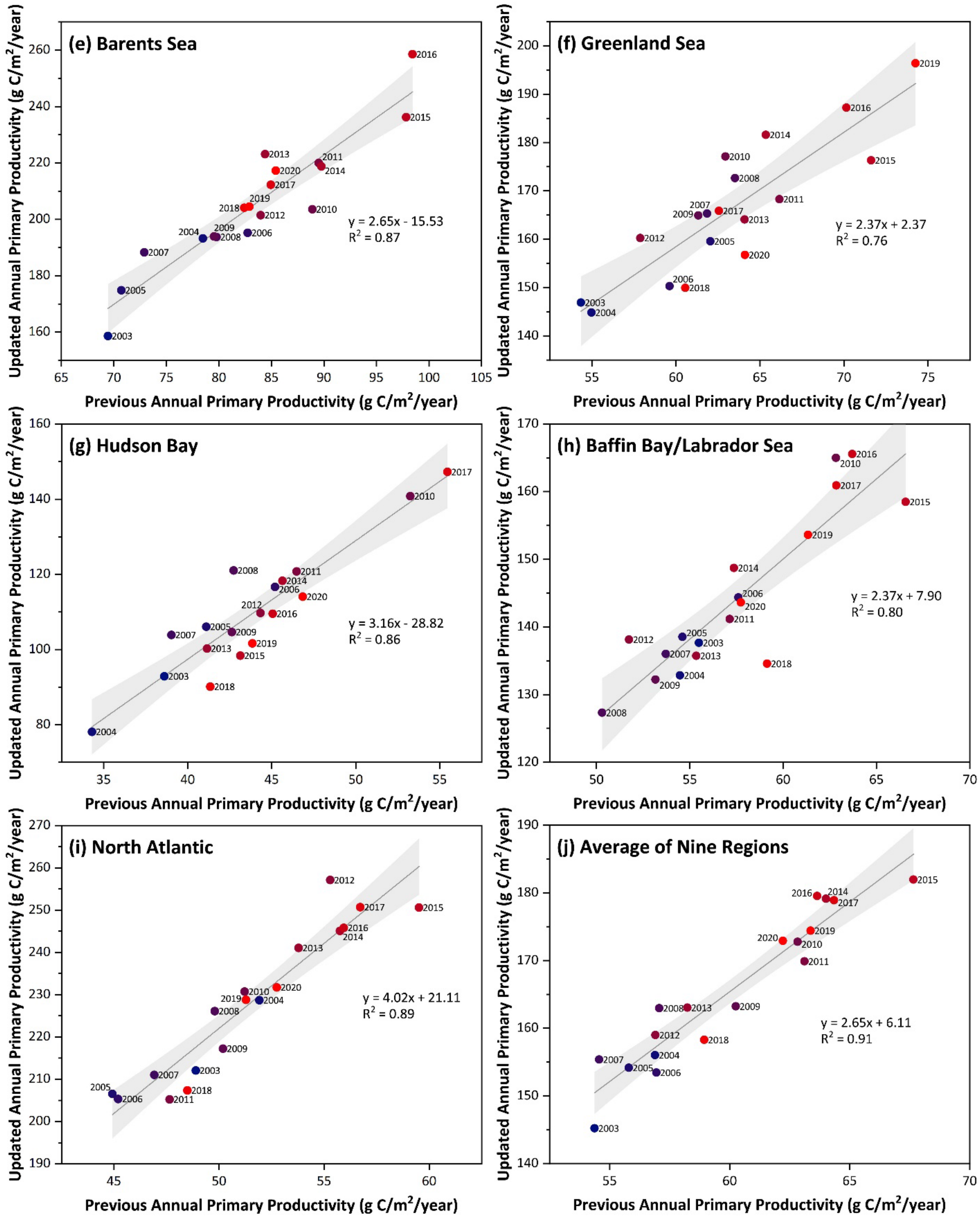


Fig. 1. Comparison between previously reported annual primary productivity and updated primary productivity for (a-i) the nine regions investigated across the Arctic as well as (j) the average of those nine regions for the years 2003-20. Linear regressions with 95% confidence intervals (shaded regions) are shown, with the year of each datapoint color coded using the color scale shown in (a).

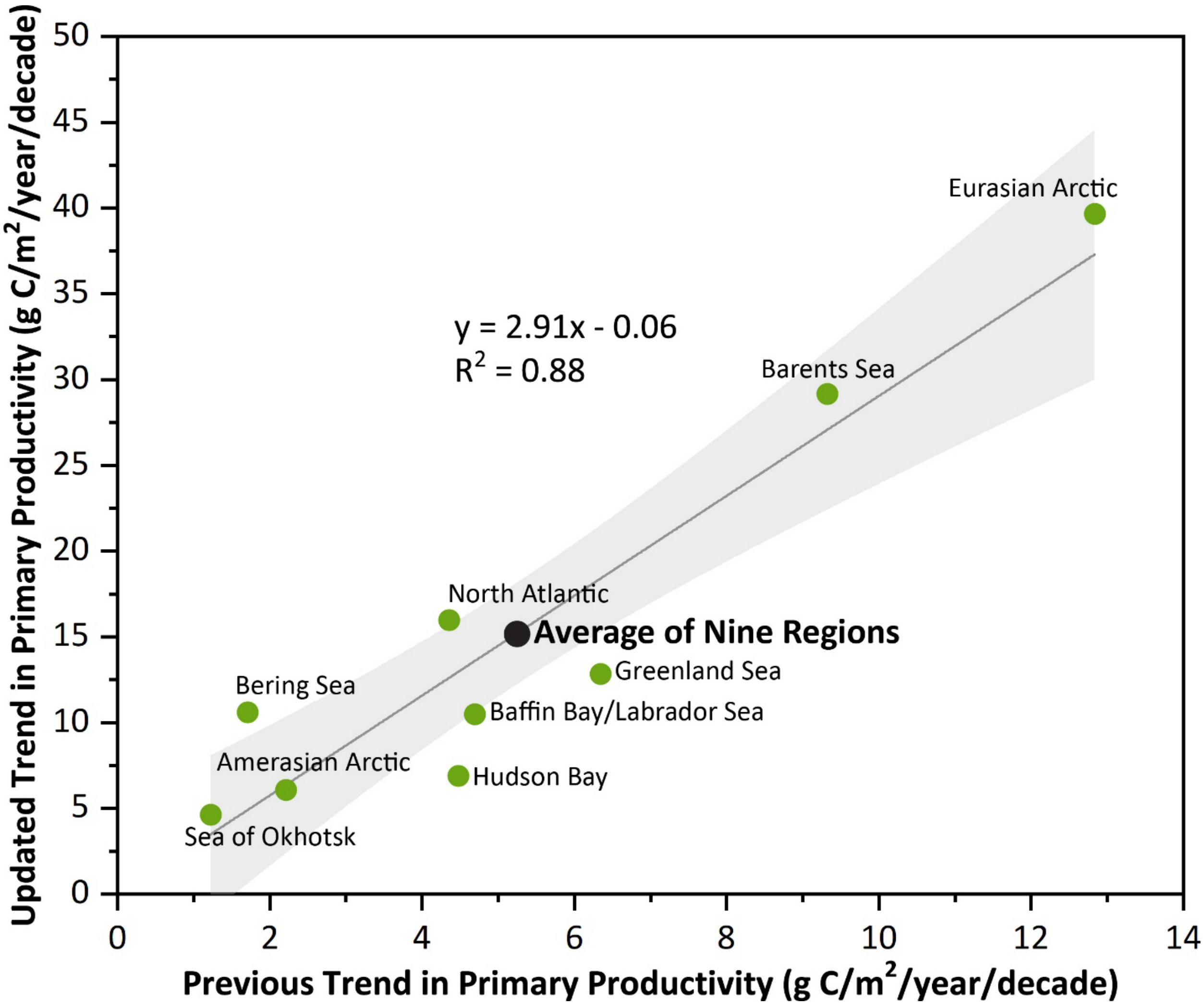


Fig. 2. Comparison between previously reported trends in primary productivity and updated trends in primary productivity for the nine regions investigated across the Arctic as well as the average of those nine regions over the years 2003-20. The linear regression with 95% confidence intervals (shaded regions) is shown. On average, the updated trends are 2.91 times steeper than the previous trends.

Table 1. Comparison of updated vs. previous primary productivity values and trends in primary productivity over the years 2003-20. Reported slope values represent modeled mean ratios of updated to previous primary productivity values. **Since 2015, each essay has provided the simple arithmetic mean of primary productivity of the nine Arctic regions. The slope of the updated vs. previous values of those arithmetic means over 2003-20 are reported here (and also shown in Fig. 1j). The previous and updated trends over time (2003-20) in primary productivity of those arithmetic means of the nine regions are also reported here (and shown as the black datapoint in Fig. 2).*

Region	Slope of Updated vs. Previous Primary Productivity Values, 2003-20	Trend in Primary Productivity, 2003-20 (g C/m^2/year/decade)	
		Previous	Updated
Eurasian Arctic	2.82	12.83	39.71
Amerasian Arctic	2.40	2.21	6.11
Sea of Okhotsk	2.88	1.22	4.66
Bering Sea	3.50	1.70	10.64
Barents Sea	2.65	9.32	29.19
Greenland Sea	2.37	6.34	12.87
Hudson Bay	3.16	4.47	6.92
Baffin Bay/Labrador Sea	2.37	4.69	10.52
North Atlantic	4.02	4.35	16.01
Average of nine regions*	2.65	5.24	15.18

In summary, with the updated values we now report primary productivity values that are on average 2.65 times higher and trends that are on average 2.91 times steeper than the previous, erroneously reported primary productivity values. Given the linear relationships between previous and updated values, the rankings of trends remain similar with the Eurasian Arctic and Barents Sea exhibiting the greatest trends in primary productivity over the years 2003-20. These updated rates of primary production provide those interested in incorporating primary productivity values into modeling and other synthesis efforts with accurate estimates of organic carbon generation across Arctic waters based on Behrenfeld and Falkowski (1997) and the OISSTv2 SST data.

References

Behrenfeld, M. J., and P. G. Falkowski, 1997: Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnol. Oceanogr.*, **42**(1), 1-20, https://doi.org/10.4319/lo.1997.42.1.0001.

Comiso, J., 2010: Polar Oceans from Space. Vol. 41. Springer Science & Business Media.

Frey, K. E., J. C. Comiso, L. W. Cooper, L. B. Eisner, R. R. Gradinger, J. M. Grebmeier, and J. -É. Tremblay, 2017: Arctic Ocean primary productivity. *Arctic Report Card 2017*, J. Richter-Menge, J. E. Overland, J. T. Mathis, and E. Osborne, Eds., https://doi.org/10.25923/8ntk-7817.

Frey, K. E., J. C. Comiso, L. W. Cooper, R. R. Gradinger, J. M. Grebmeier, and J. -É. Tremblay, 2015: Arctic Ocean primary productivity. *Arctic Report Card 2015*, M. O. Jeffries, J. Richter-Menge, and J. E. Overland, Eds., https://doi.org/10.25923/8h3d-5v51.

Frey, K. E., J. C. Comiso, L. W. Cooper, R. R. Gradinger, J. M. Grebmeier, and J. -É. Tremblay, 2016: Arctic Ocean primary productivity. *Arctic Report Card 2016*, J. Richter-Menge, J. E. Overland, and J. T. Mathis, Eds., https://doi.org/10.25923/kgx6-f630.

Frey, K. E., J. C. Comiso, L. W. Cooper, J. M. Grebmeier, and L. V. Stock, 2018: Arctic Ocean primary productivity: The response of marine algae to climate warming and sea ice decline. *Arctic Report Card 2018*, E. Osborne, J. Richter-Menge, and M. Jeffries, Eds., https://doi.org/10.25923/krcx-z320.

Frey, K. E., J. C. Comiso, L. W. Cooper, J. M. Grebmeier, and L. V. Stock, 2019: Arctic Ocean primary productivity: The response of marine algae to climate warming and sea ice decline. *Arctic Report Card 2019*, J. Richter-Menge, M. L. Druckenmiller, and M. Jeffries, Eds., https://doi.org/10.25923/bw4d-my28.

Frey, K. E., J. C. Comiso, L. W. Cooper, J. M. Grebmeier, and L. V. Stock, 2020: Arctic Ocean primary productivity: The response of marine algae to climate warming and sea ice decline. *Arctic Report Card 2020*, R. L. Thoman, J. Richter-Menge, and M. L. Druckenmiller, Eds., https://doi.org/10.25923/vtdn-2198.

Frey, K. E., J. C. Comiso, L. W. Cooper, J. M. Grebmeier, and L. V. Stock, 2021: Arctic Ocean primary productivity: The response of marine algae to climate warming and sea ice decline. *Arctic Report Card 2021*, https://doi.org/10.25923/kxhb-dw16.

Lewis, K. M., G. L. van Dijken, and K. R. Arrigo, 2020: Changes in phytoplankton concentration now drive increased Arctic Ocean primary production. *Science*, **369**, 198-202, https://doi.org/10.1126/science.aay8380.

Smith, Jr., W. O., and J. C. Comiso, 2008: The influence of sea ice on primary production in the Southern Ocean: A satellite perspective. *J. Geophys. Res.*,**113**, C05S93, https://doi.org/10.1029/2007JC004251.

Mention of a commercial company or product does not constitute an endorsement by NOAA/OAR. Use of information from this publication concerning proprietary products or the tests of such products for publicity or advertising purposes is not authorized. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration.

December 7, 2021