Interannual to decadal variability in Subarctic Atlantic Ocean primary productivity

historical variability, dynamics, and response to warming

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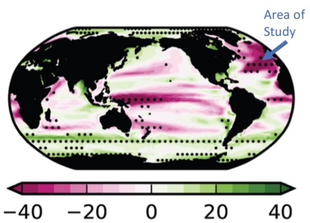
Introduction

The Subarctic Atlantic Ocean is characterized by high annual primary productivity and prominent spring phytoplankton blooms, which sustain higher trophic levels including fisheries and export carbon to the deep ocean. Earth system models indicate that global warming will cause strong ~ 50% reductions in Subarctic Atlantic phytoplankton productivity and biomass.

Figure 1. Multi-model mean change in net primary productivity between early and late 21st century in a high-emissions global warming scenario (g C/m^2/yr). From Kwiatkowski et al. (2020).



We quantify interannual to multidecadal variability of Subarctic Atlantic phytoplankton productivity, specifically annual new production, May-August mean chlorophyll concentration, and March nitrate, and their changes in a high-emissions 21st century global warming scenario.

Methods

We use a large ensemble of 32 simulations of the fully-coupled Community Earth System Model (CESM) in a high-emissions 21st-century global warming scenario. The internal climate variability is not constrained by observations, so the simulated variability should be validated by comparing the statistics with observations. We focus on standard deviations and coefficient of variations integrated over the Subarctic Atlantic (70 W – 10 E, 45 N – 75 N). But spatial anomaly patterns are qualitatively similar too.

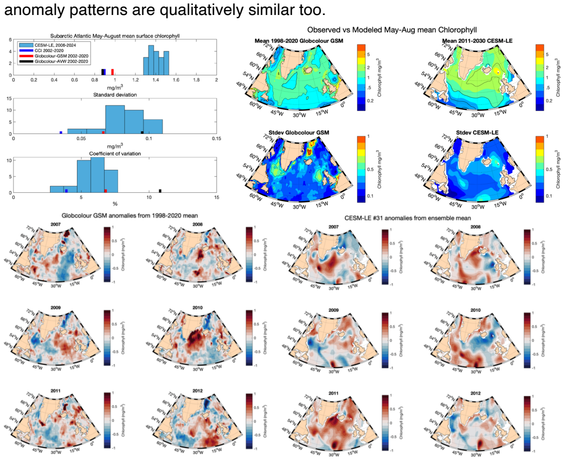


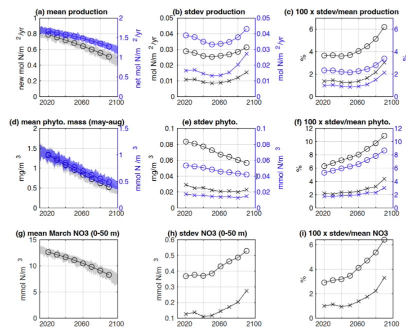
Figure 2. Comparisons between the CESM-LE and several multimission satellite measures of May-Aug surface chlorophyll. Clockwise from top left: area-integrated Subarctic Atlantic statistics, maps of the climatological means and standard deviations, and example anomaly maps from the Globcolour GSM product and simulation #31 in the years 2007-2012.

Increasing interannual and multidecadal variability

Productivity, biomass and wintertime nutrient concentrations decline, but the coefficients of variation at interannual and decadal timescales all increase.

Even more surprisingly, the raw standard deviations of productivity and March nitrate both increase non-monotonically with warming.

Figure 3. The changing area-integrated statistics of Subarctic Atlantic ocean productivity (mean, standard deviation, and coefficient of variation) in the global warming scenario. The variables include (a-c) annual new (black) and net (blue) primary production, (d-f) May-August mean phytoplankton chlorophyll (black) and nitrogen (blue), and (g-i) upper-ocean nitrate during March. The shading in the left panels captures the spread among 32 simulations and the black circles represent 20-year and ensemble means. In the center and right column, the circle represents interannual variability, whereas the cross represents multi-decadal variability.



Strengthening nutrient control of variability

March nutrient concentration anomalies explain most of the variance in the area-integrated Subarctic Atlantic annual new production anomalies and explain nearly all the variance by the end of the 21st century scenario.

The slope of the regression between new production and March nitrate has units of meters and values similar to the euphotic depth, which indicates approximate mass balance between the annual new production anomaly and the nutrient anomaly in the euphotic zone in March.

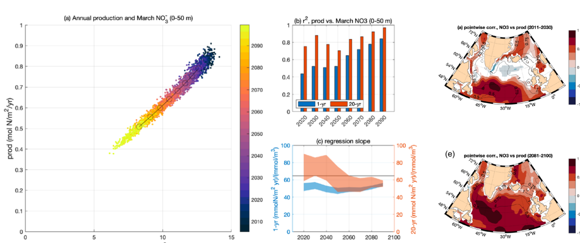


Figure 4. Comparisons between the annual new production and March nitrate in CESM-LE: (a) a scatter plot of every year (95) from each ensemble member (32) along with the means in 20-year windows (o); (b-c) the correlation coefficients (r^2) and slopes associated with linear regressions of area-integrated new production anomalies and March nitrate anomalies at interannual (blue) and multi-decadal (orange) timescales in 20-year windows; (d-e) show the correlation coefficients (r) computed in each 1-degree box. The results are similar but with larger r at 20-year timescales (not shown).

Rising sensitivity to physical variability

The annual productivity anomalies are sensitive to variability in the winter mixed layer depth and the meridional overturning circulation; these sensitivities strengthen with global warming.

The increasing variability in productivity and nutrients with warming is first a consequence of the increasing sensitivity of productivity to these physical drivers and second a consequence of the increasing coefficients of driver variation.

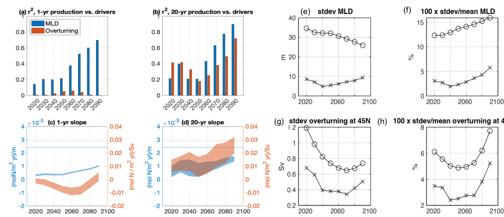


Figure 5. The coefficients of variation of the winter mixed layer depth and meridional overturning at 45 N rise non-monotonically with warming (f,h), although the variances generally decline (e,g). In addition, global warming increases the sensitivity of annual new production to these drivers, which is reflected in greater correlation coefficients (a-b) and regression slopes (c-d).

Key Points

In the Subarctic Atlantic, global warming reduces average biological productivity while increasing interannual and multidecadal variability

Productivity variability increases because wintertime surface nutrient variability increases

Wintertime nutrient variability increases because it becomes more sensitive to variability in meridional overturning and winter mixing and because their coefficients of variation increase non-monotonically

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