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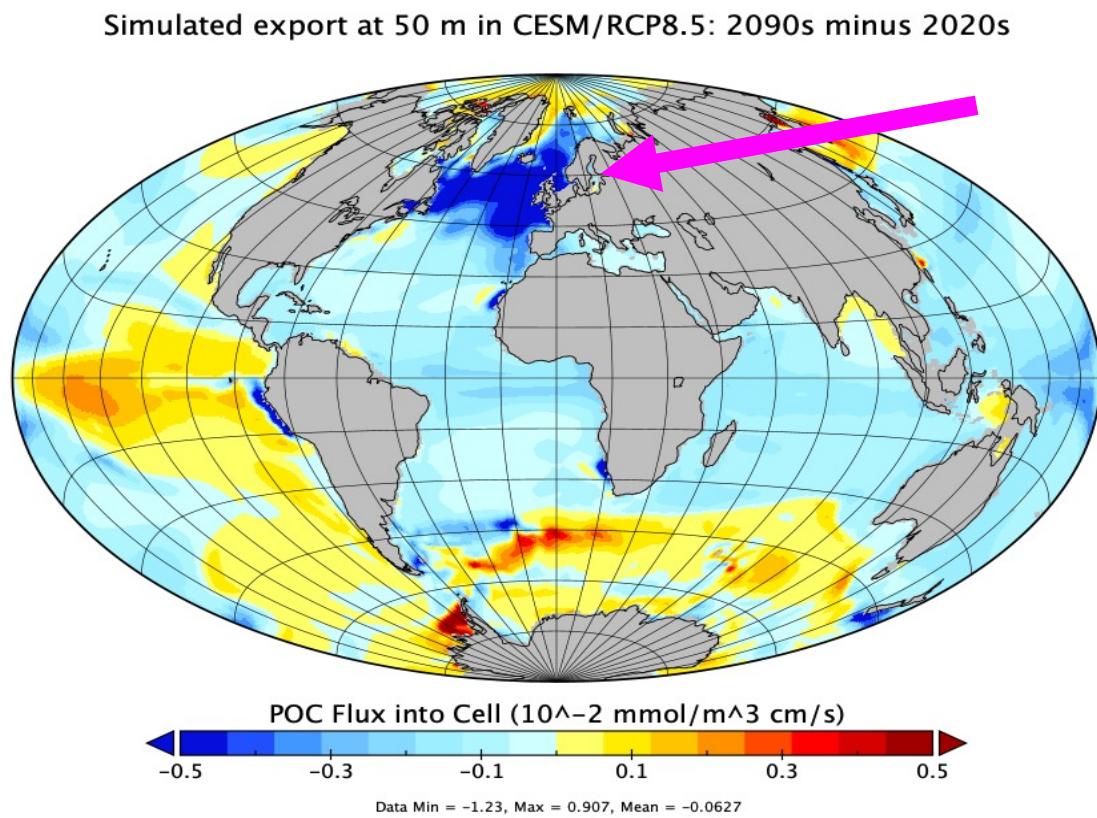
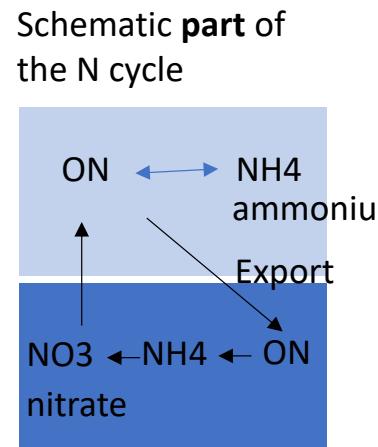
Elucidating the role of ocean circulation in changing North Atlantic nutrients and biological productivity

Funded by
NASA 2020 New Investigator Program in Earth Science
NASA Physical Oceanography Program



MOTIVATION

Earth system models indicate that the Subarctic Atlantic biological productivity is particularly sensitive to global warming



PRIOR CONTRIBUTIONS

Four papers...

2019

4

On the Role of the Gulf Stream in the Changing Atlantic Nutrient Circulation During the 21st Century

Daniel B. Whitt

ABSTRACT

The Gulf Stream transports macronutrients poleward as part of the Atlantic meridional overturning circulation (AMOC). Scaling shows that this advective transport is greater than diapycnal transport from deep convection in the North Atlantic and is therefore crucial for maintaining the nutrient supply to the subpolar gyre. An increase in meridional overturning of the AMOC 5% would increase the Gulf Stream volume by 2020. The declining Gulf Stream volume explains 40% of the increase in macronutrient transports in the North Atlantic. As a result, the declining nitrate transport in the AMOC is the driving factor of the declining export of macronutrients from the North Atlantic. As a result, the declining nitrate entrainment from water with $> 27.5 \text{ kg m}^{-3}$ is only 0.44 kmol s per year. A review of various small-scale ocean physical processes suggests that the projected decline in the Gulf Stream nutrient flux is qualitatively robust to uncertainties associated with ocean physics.

4.1. INTRODUCTION

The Gulf Stream is the upper limb of the Atlantic meridional overturning circulation (AMOC) and the western boundary current of the North Atlantic subtropical gyre. The Gulf Stream is also a nutrient stream. It transports macronutrients (nitrate, phosphate, silicate) necessary for primary production from the eastern continental margin of the United States from the subtropical gyre to the subpolar gyre. At Cape Hatteras, the Gulf Stream separates from the coast and carries its nutrients to the northeast off the continental slope and into deep water. There, waters of recent tropic, subtropical, and polar origin converge in both the volume and nutrient transport, in a great junction of the global ocean circulation.

National Center for Atmospheric Research, Boulder, CO, USA

Kuroshio Current: Physical, Biogeochemical, and Ecosystem Dynamics, Geophysical Monograph 245, First Edition. Edited by Takeyoshi Nagai, Hiroaki Saito, Koji Suzuki, and Motonori Takahashi. © 2019 American Geophysical Union. Published 2019 by John Wiley & Sons, Inc.

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2020

Slower nutrient stream suppresses Subarctic Atlantic Ocean biological productivity in global warming

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Earth system models (ESMs) project that global warming will suppress biological productivity in the Subarctic Atlantic Ocean as it impairs the surface nutrient supply. The drivers of nutrient supply: vertical mixing and meridional circulation, are both altered by global warming. The surface buoyancy in the ocean and the relative importance of the physical theory of how mixing, circulation, and productivity respond to increasing surface buoyancy in 21st-century global warming are not well understood. The theory suggests that the reduced northward nutrient transport, resulting from the reduced meridional circulation, is the primary driver of the decline in biological productivity. For example, consider the horizontally averaged dynamics of surface nitrate production in the subpolar gyre of the North Atlantic. As a result, the theory suggests that the declining Gulf Stream nutrient transport in the North Atlantic is the driving factor of the declining nitrate entrainment from water with $> 27.5 \text{ kg m}^{-3}$ is only 0.44 kmol s per year. A review of various small-scale ocean physical processes suggests that the projected decline in the Gulf Stream nutrient flux is qualitatively robust to uncertainties associated with ocean physics.

Author contributions: D.B.W. performed the research, performed the numerical experiments, and wrote the paper. M.F.J. helped design the model and provided the model code. Both authors contributed to the manuscript.

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REFERENCES AND NOTES. The authors declare no conflicts of interest with respect to their affiliation or funding sources. This work is available online in its entirety in its final form at <https://doi.org/10.1029/2019GL080716>.

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How will marine biogeochemistry and
ecosystems evolve in a changing climate?



How does the ocean physics influence marine
biogeochemistry and ecosystems?

SUBARCTIC ATLANTIC OCEAN

Seasonal cycle

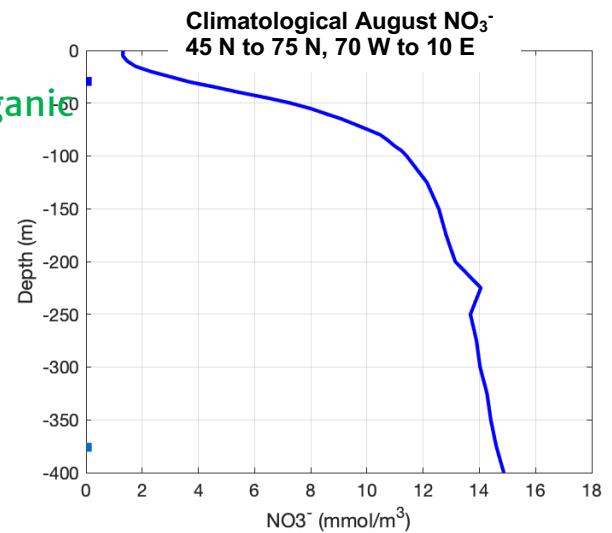
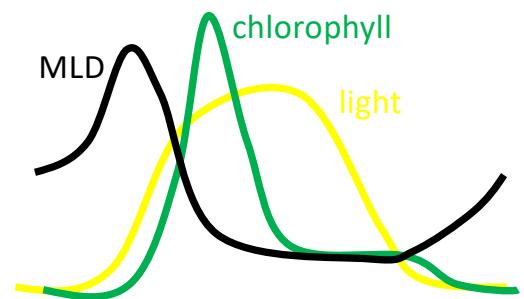
Phytoplankton require light and nutrients such as nitrate (NO_3^-) to grow.

NO_3^- is low at the surface and replete at depth during summer.

Wintertime vertical mixing replenishes NO_3^-

Spring solar radiation shoals the mixing layer, and phytoplankton draw down NO_3^-

Sinking detrital material is remineralized back to NO_3^- in the seasonal thermocline or deeper



Dynamics are essentially local/vertical/1-D

SUBARCTIC ATLANTIC OCEAN

Annual mean

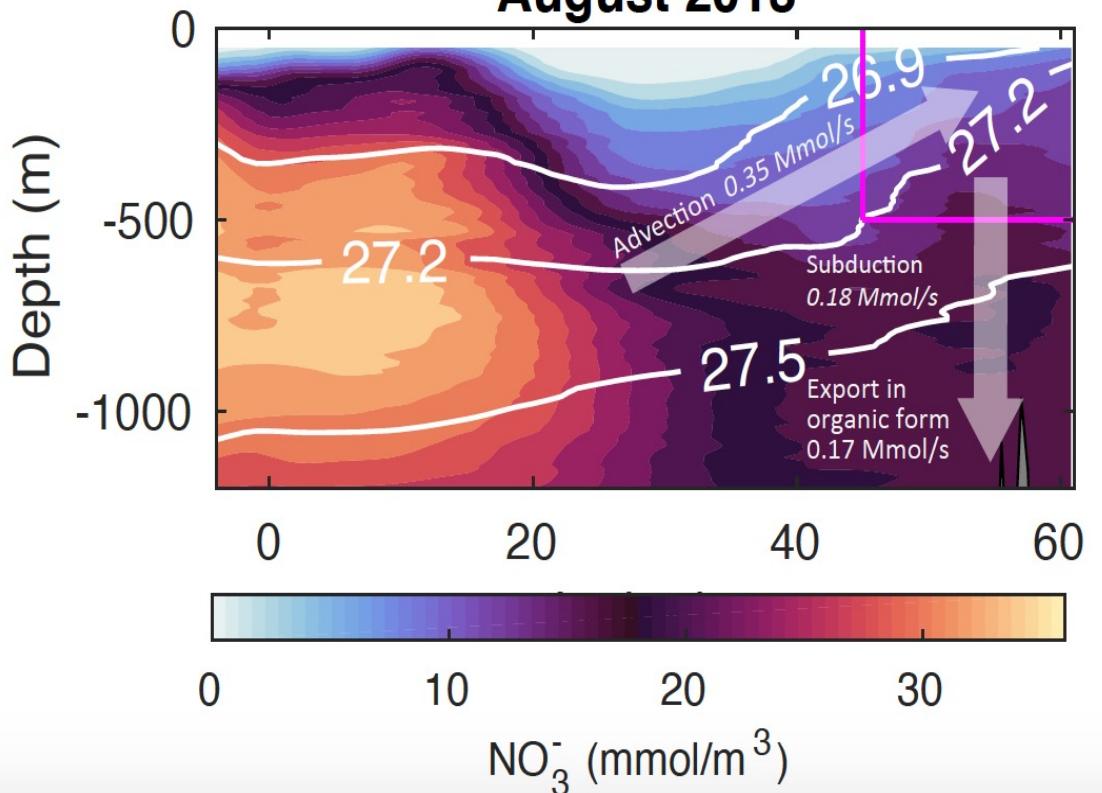
Export & subduction to depths below the winter mixed layer is replenished by meridional circulation

To put these numbers in perspective:
Global Anthropogenic N fixation $\sim .475 \text{ Mmol/s}$
(Fowler et al. 2013)

Advective replenishment timescale
for Subpolar North Atlantic NO_3^- above 1 km:
 $(200 \text{ Gmol}) / (0.3 \text{ Mmol/s}) \sim 20 \text{ years}$

(B) Observed meridional section

August 2013





How ***does*** the MOC participate in North Atlantic biogeochemistry?

We can only understand it after we can model it.

Evaluation of ECCO-Darwin Zonal-mean Atlantic Nitrate

Annual mean

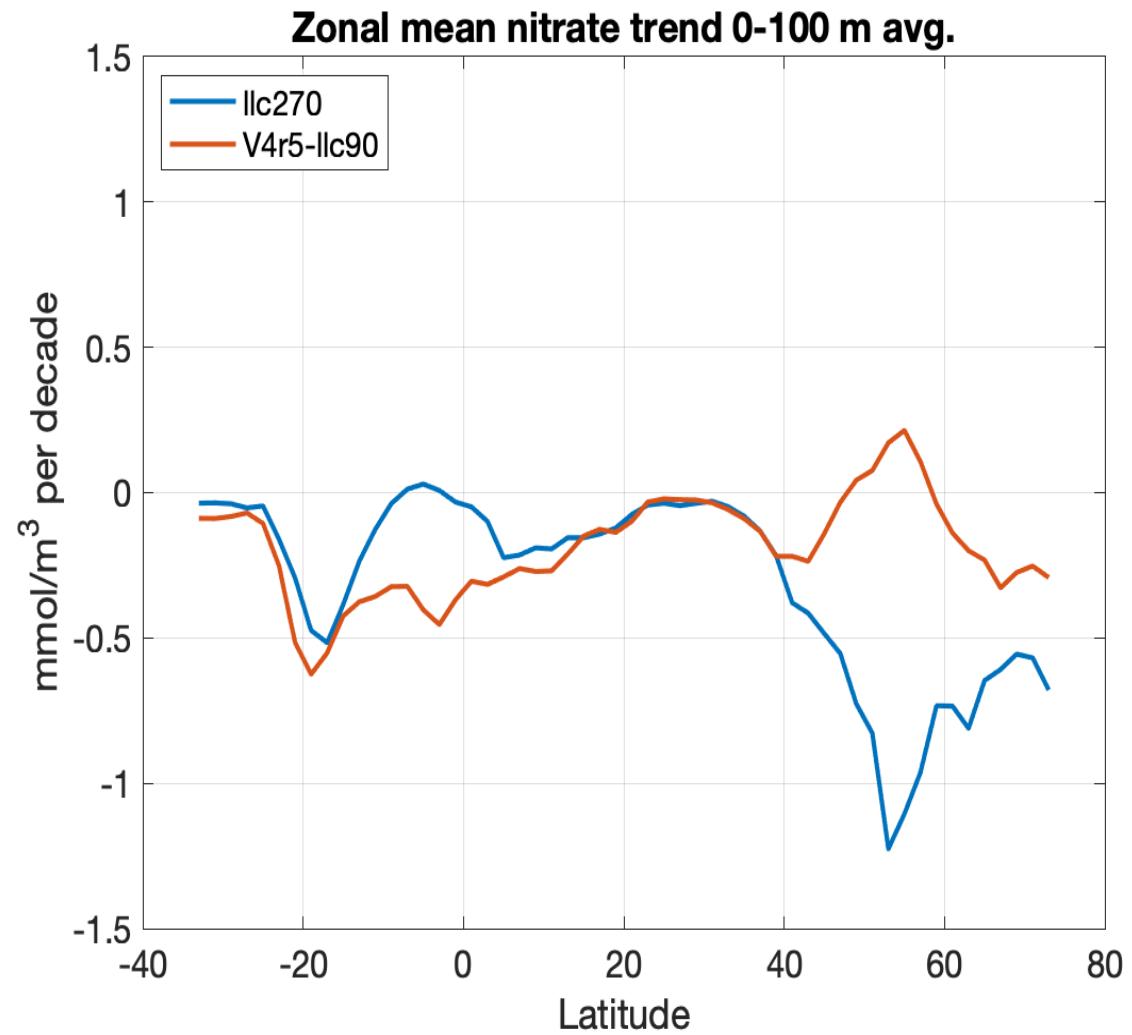
Below 500 m:

Nitrate $> 18 \text{ mmol/m}^3$

Trends $\sim 0.1\text{-}1 \text{ mmol/m}^3/\text{decade}$

Biases $\sim 1\text{-}3 \text{ mmol/m}^3$ are small

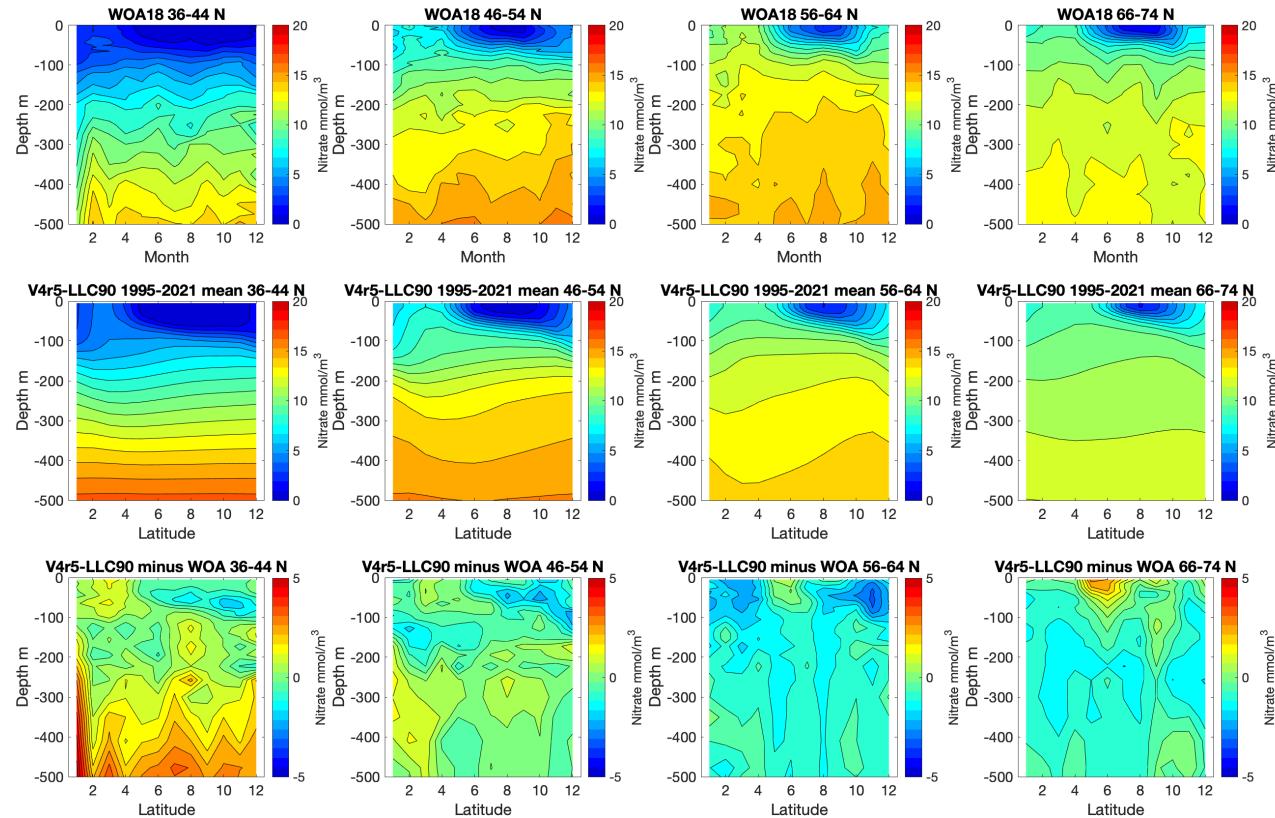
Patterns are qualitatively reasonable in the upper ocean, but exhibit large biases and trends compared to low reference concentrations.



Seasonal cycle in the Subarctic Atlantic

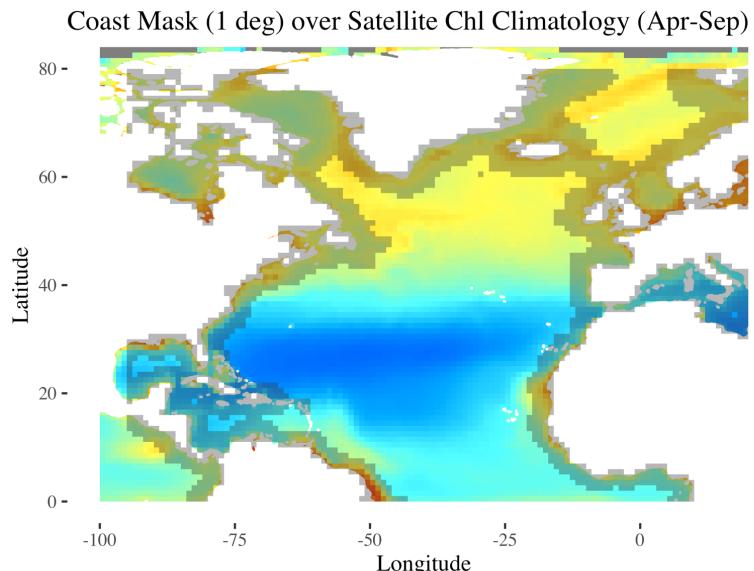
V4r5 is fairly realistic

LLC270 (not shown) has
low-bias that is most
pronounced in winter,
damped seasonal cycle

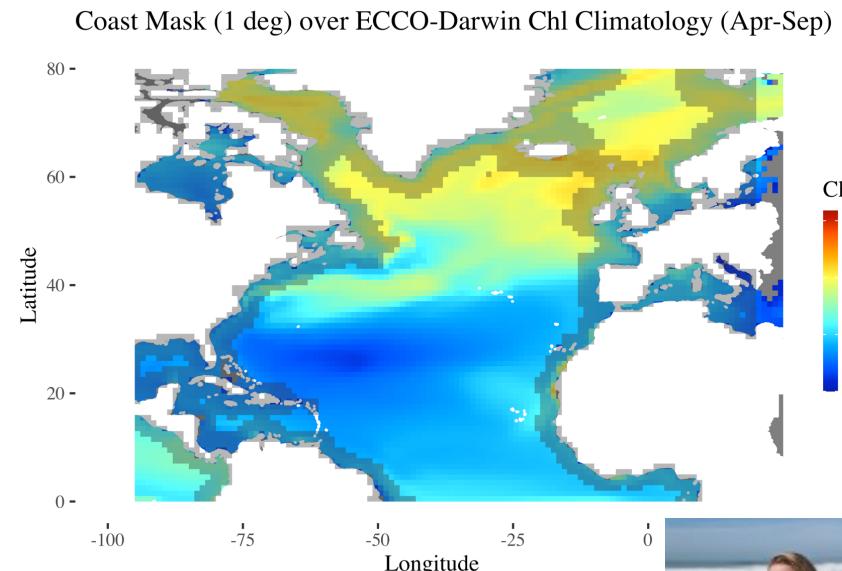


Evaluation of ECCO-Darwin
Zonal-mean Atlantic Nitrate

State estimates qualitatively capture climatological open-ocean chlorophyll



Low modeled growing season chlorophyll in LLC270 vs
satellite qualitatively consistent with low-nutrient biases



Post-doc Casey Schine
Now at Middlebury

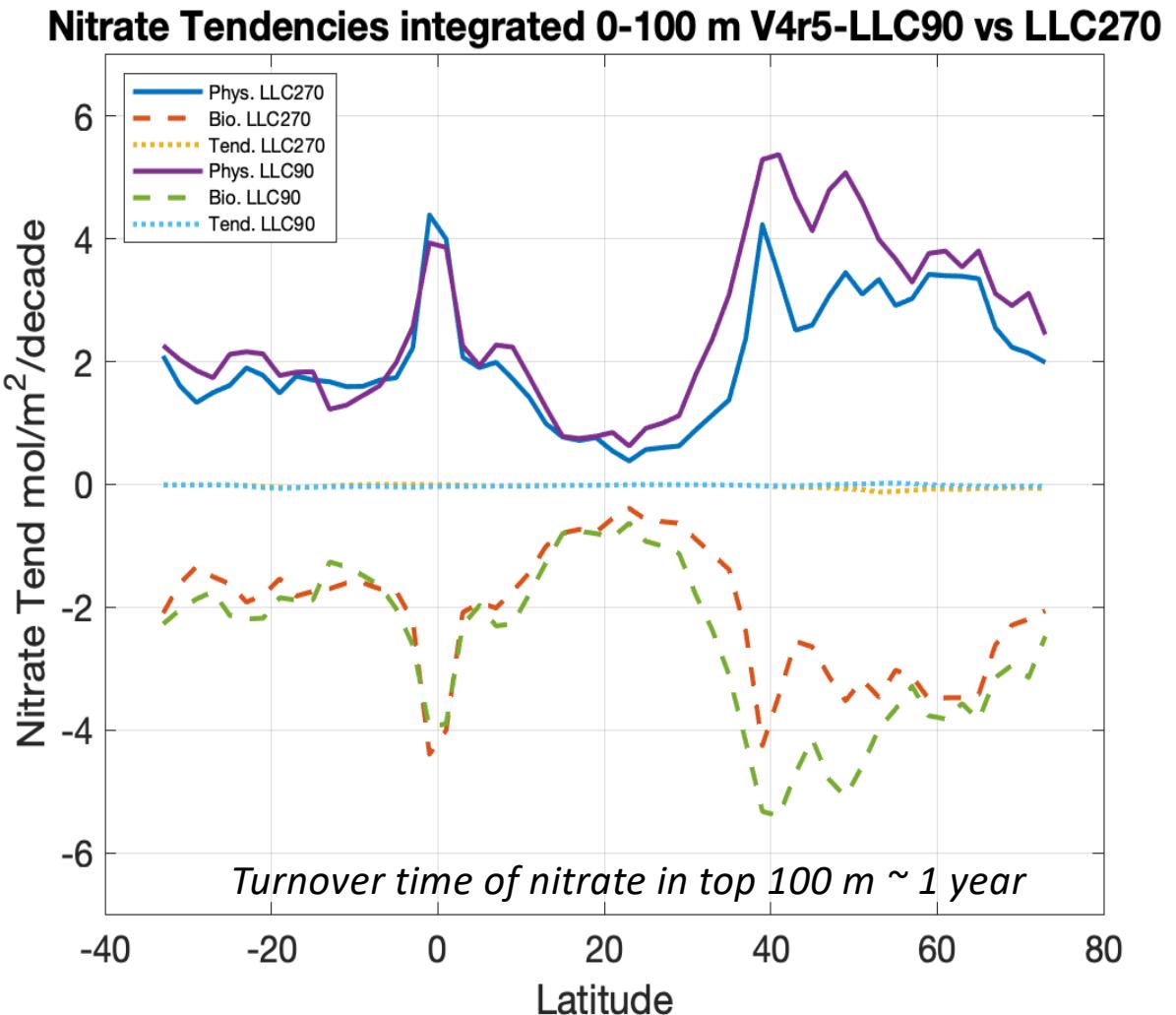


Dynamics of ECCO-Darwin Zonal-mean Atlantic Nitrate

Top 100 m

Physical transport supplies and biology consumes and exports nitrate in the upper 100 m on a timescale ~ 1 year on average.

LLC270 has lower new production, weaker biological pump in the Subarctic Atlantic

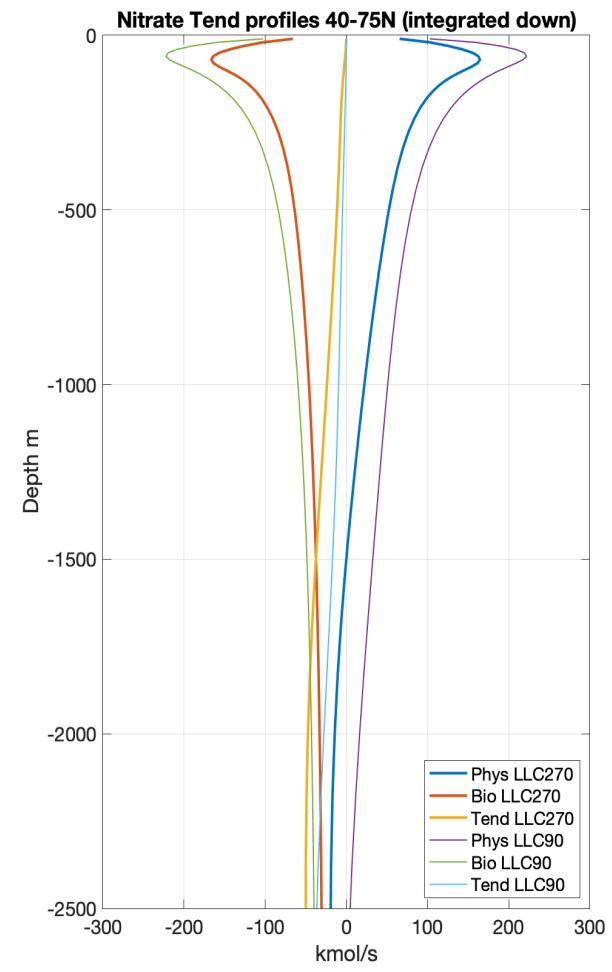
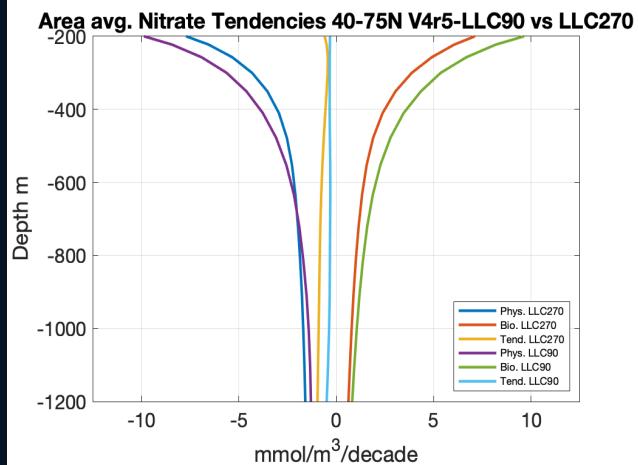
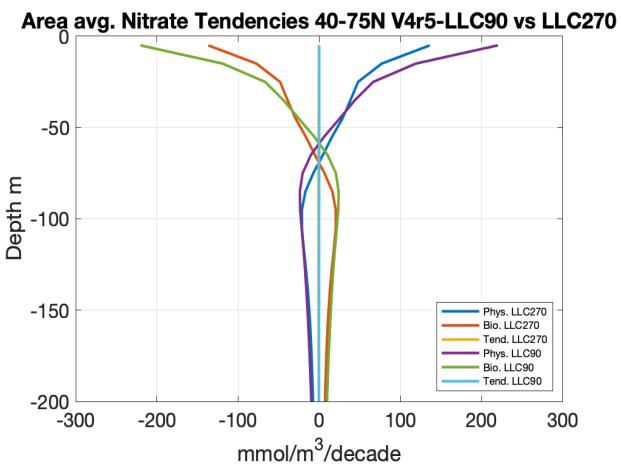


Dynamics of ECCO-Darwin
Zonal-mean Atlantic Nitrate

Subarctic Atlantic Profile

The nitrate tendency due to new productivity in the euphotic zone and remineralization at depth largely mirrors physical transport

The Subarctic Atlantic biological pump is 30-40% stronger in V4r5 than LLC270

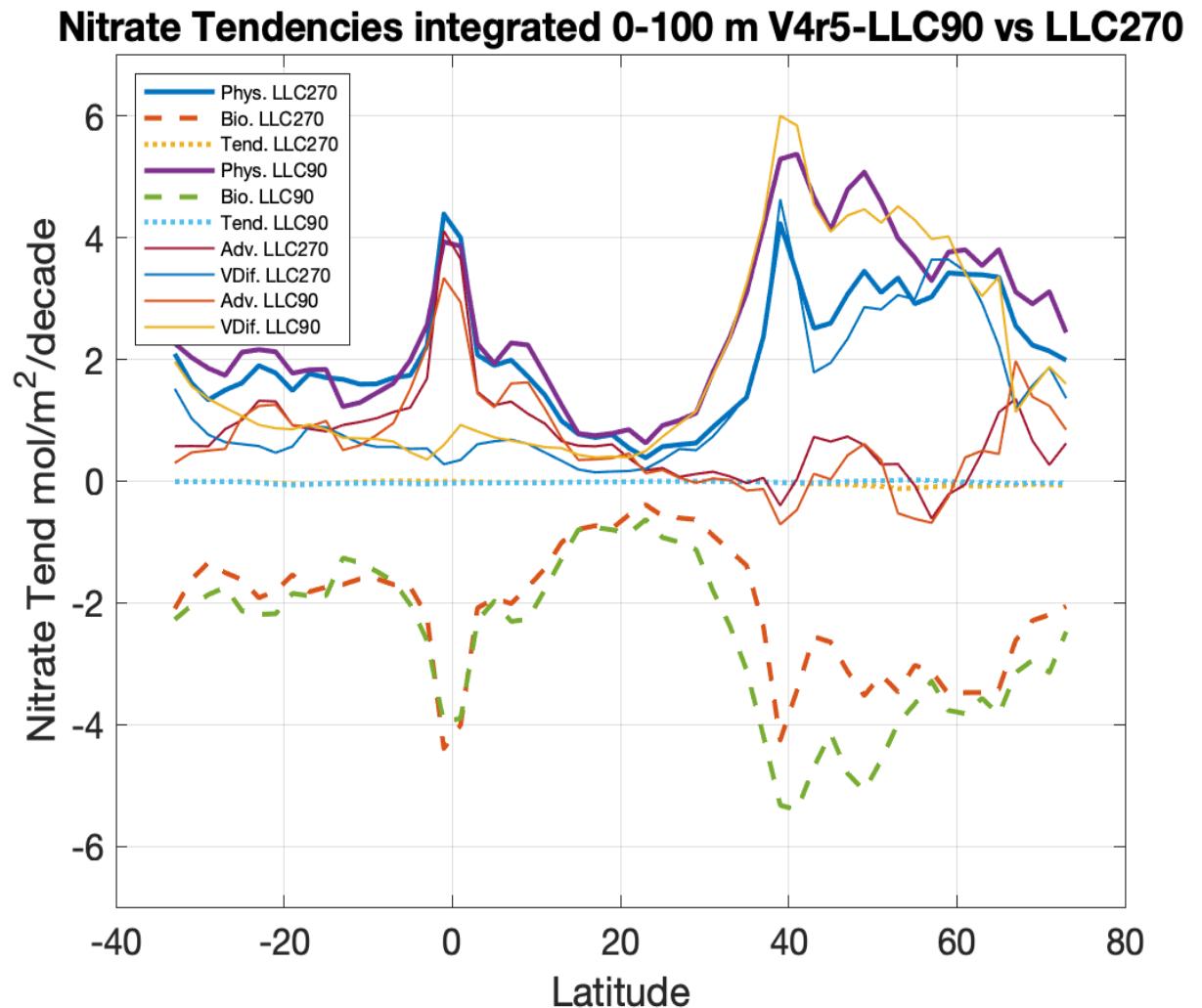


Dynamics of ECCO-Darwin
Zonal-mean Atlantic Nitrate

Separating Physical Contributions to New Production in the top 100 m

Vertical mixing dominates flux at 100 m poleward of 30°

Upwelling dominates flux at 100 m equatorward of 30°



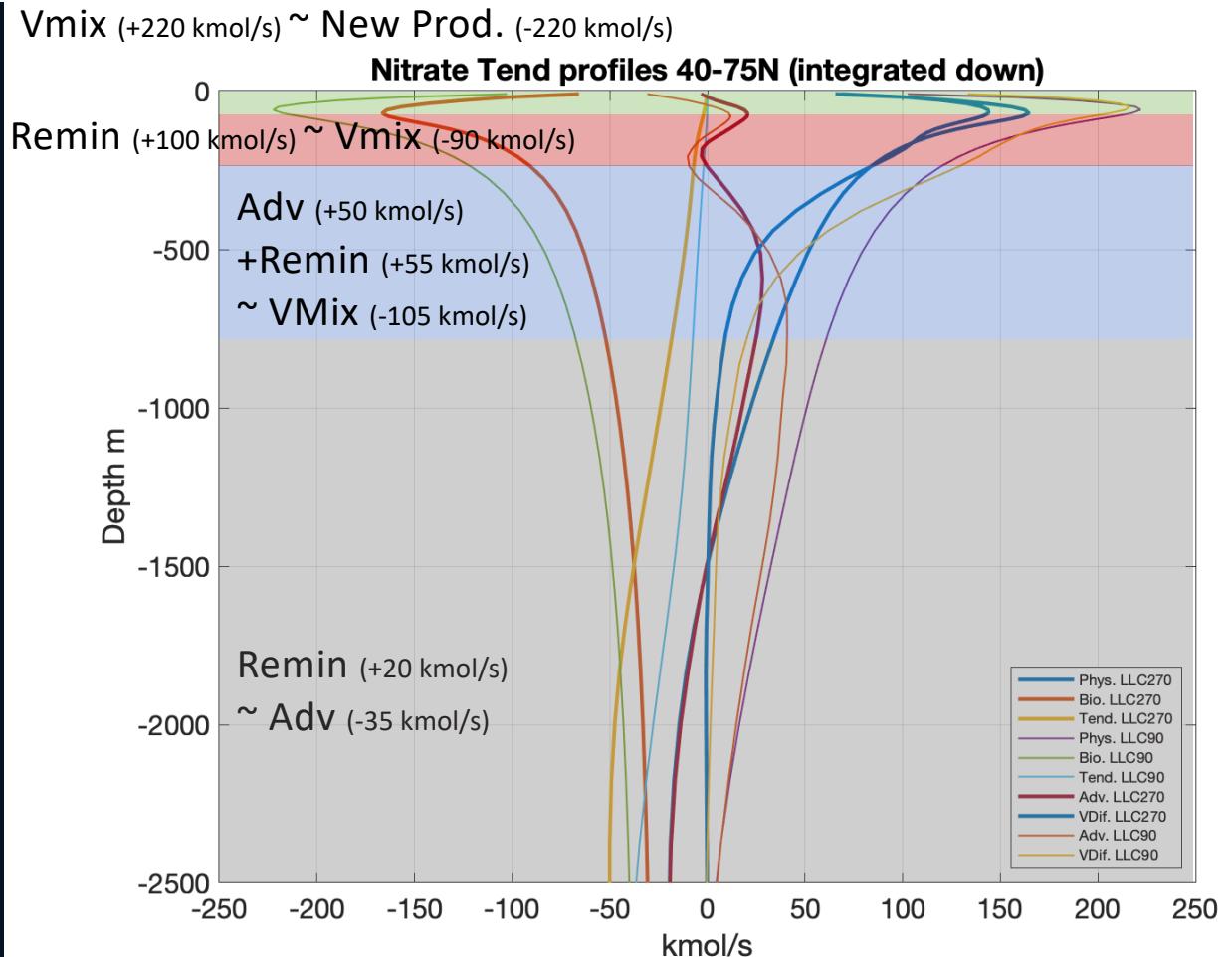
Dynamics of ECCO-Darwin
Zonal-mean Atlantic Nitrate

Separating Physical Contributions to New Production in the Subarctic Atlantic Profile

Mixing drives the shallow cycle

Advection drives the deep cycle

Dynamics are qualitatively similar in V4r5 and LLC90



Thanks

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