On the role of the Gulf Stream in the changing Atlantic nutrient circulation during the 21st century

Daniel B Whitt

Whitt (2018), in "Kuroshio Current: Physical, Biogeochemical and Ecosystem Dynamics," AGU-Wiley Geophysical Monograph Series. Edited by T. Nagai, H. Saito, K. Suzuki, and M. Takahashi. *In press.*

NCAR

Outline

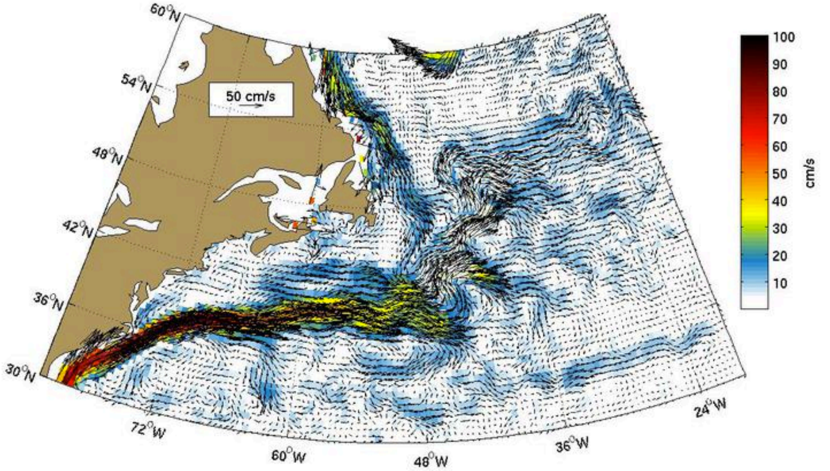
A large-scale observational description of the Gulf Stream nutrient stream

Projected decline of Gulf Stream nutrient flux in simulations with CESM, and implications

~~How small-scale processes modify AMOC and associated Gulf Stream nutrient transport~~

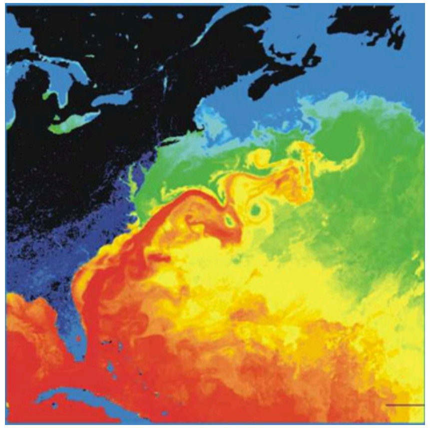
What we usually talk about when we talk about the Gulf Stream

Mean Surface Current Speed

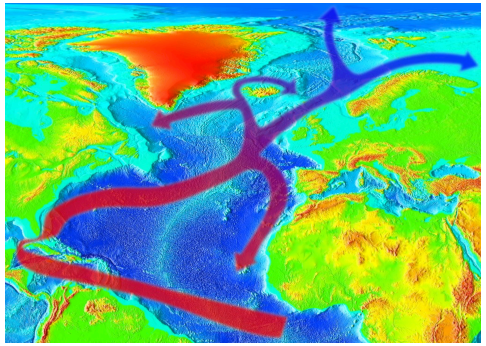


http://oceancurrents.rsmas.miami.edu/atlantic/

Sea surface temperature

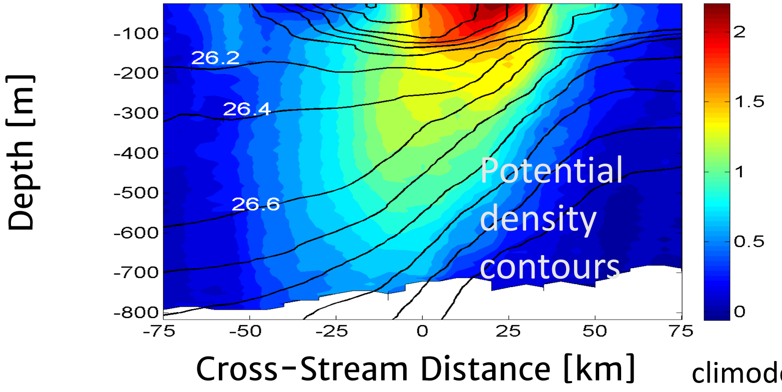


Crude schematic of upper-limb of North Atlantic circulation



Wikipedia

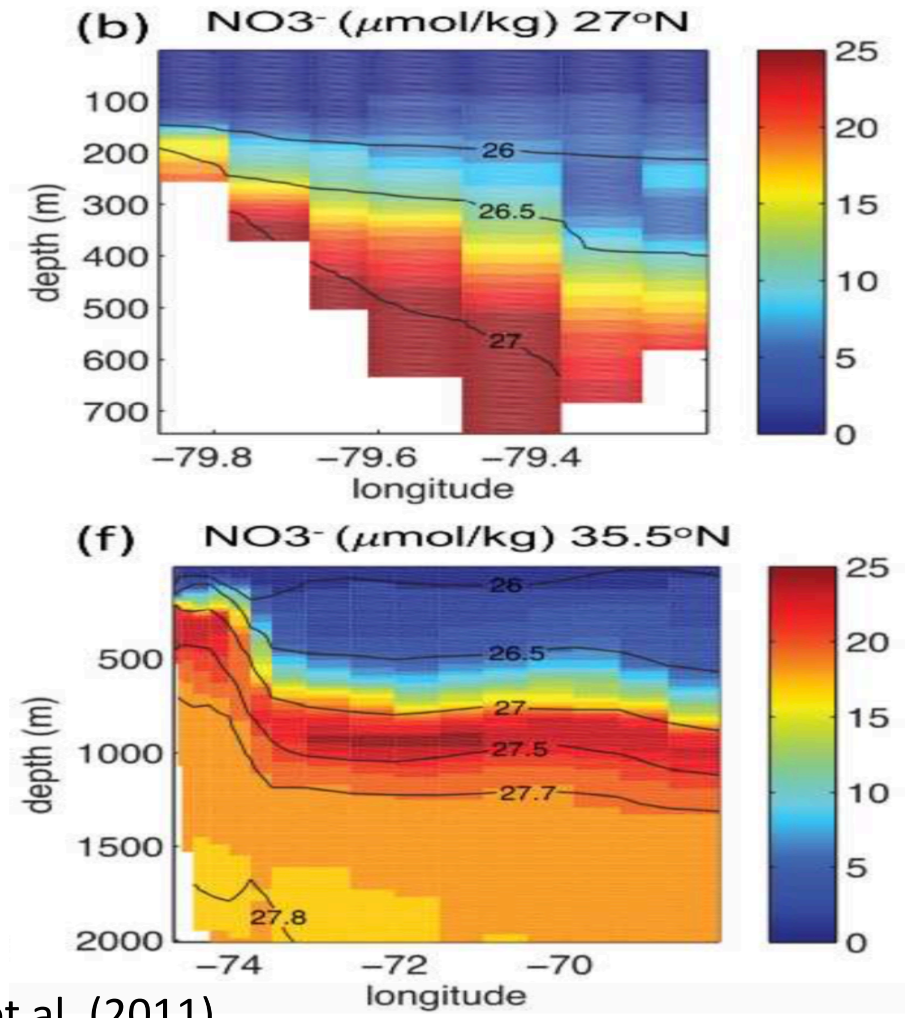
Streamwise velocity [m/s]



climode.org

- Western boundary current of subtropical gyre
- Prominent surface front, steeply sloping isopycnals
- Key pathway of Atlantic meridional overturning circulation
- Large heat, salt and water transports

Does Gulf Stream influence global biogeochemical cycles?

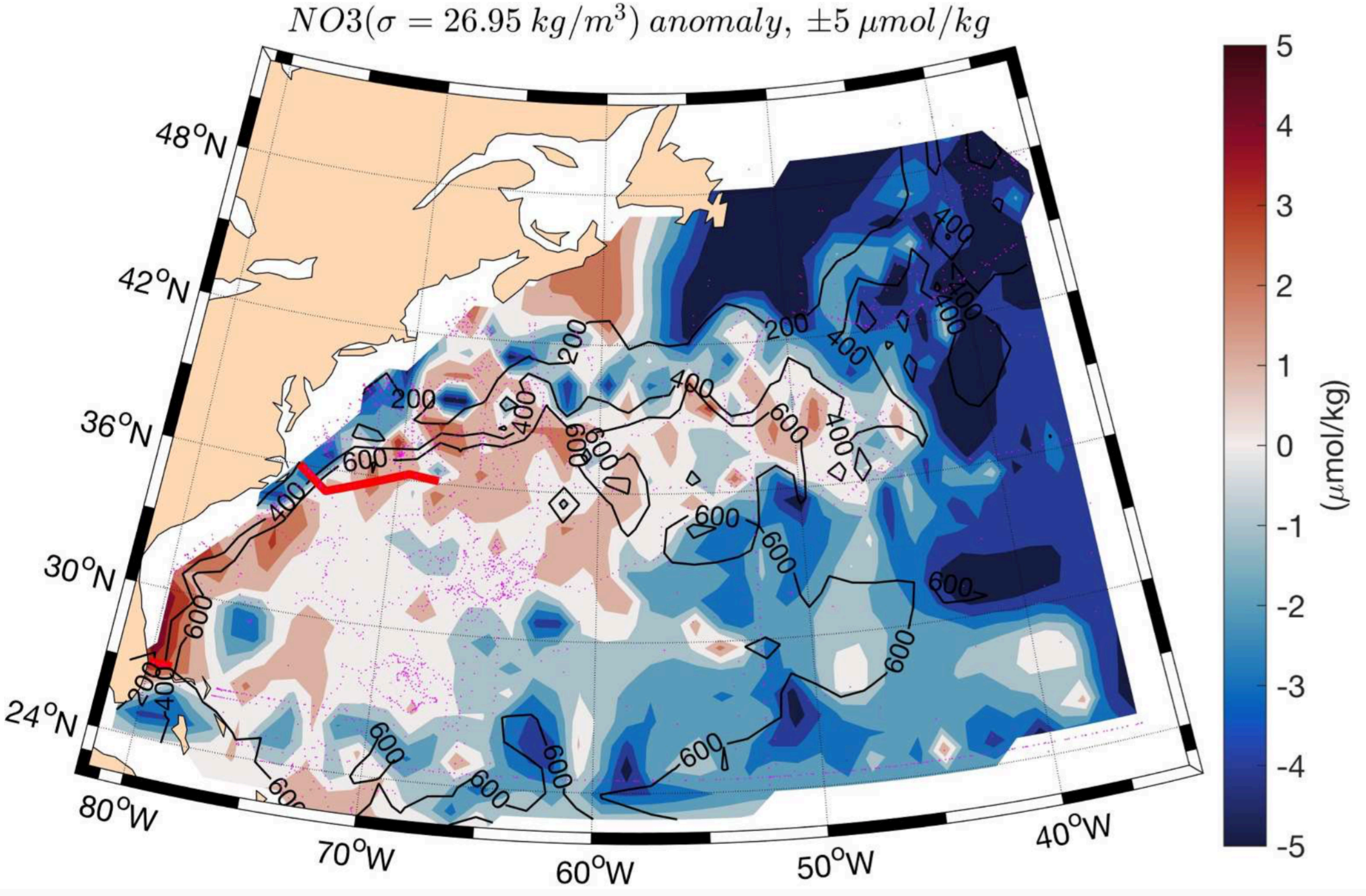


Williams et al. (2011)

Nutrients depleted at surface, maximum in the main pycnocline

Isopleths of nutrient align with sloping isopycnals across the Gulf Stream

NO3 is elevated in the Gulf Stream on subsurface isopycnals



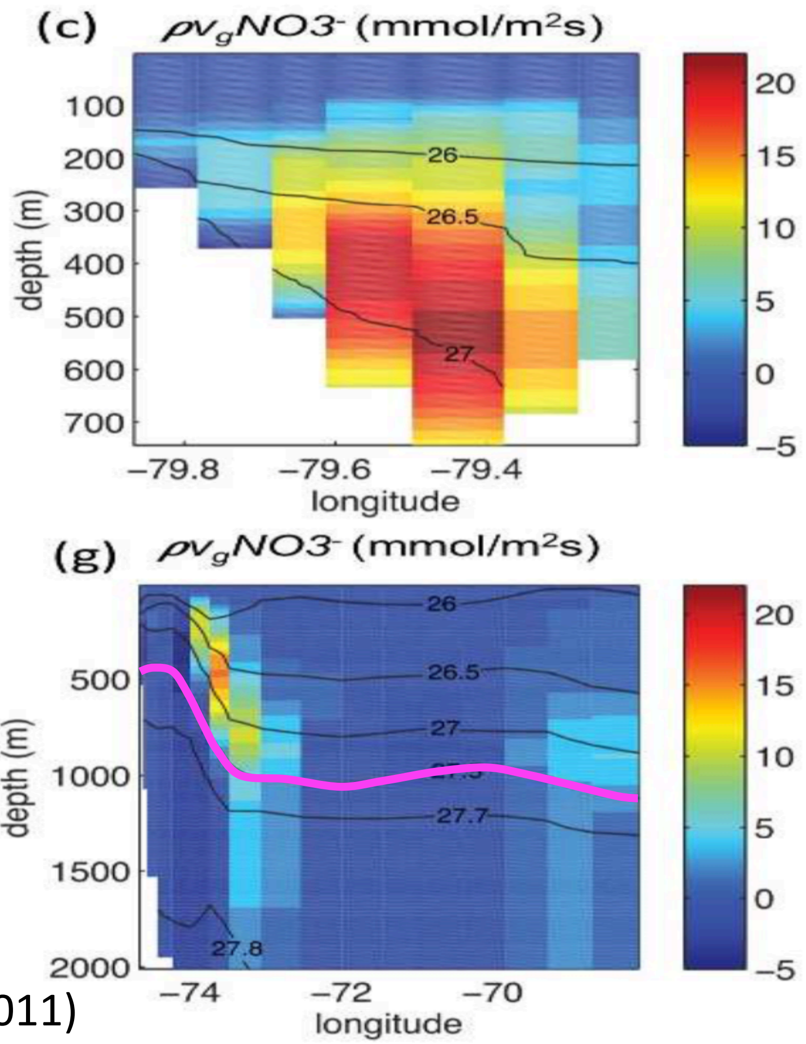
Whitt (2018)

Gulf Stream transports vast quantities of nutrients below the surface

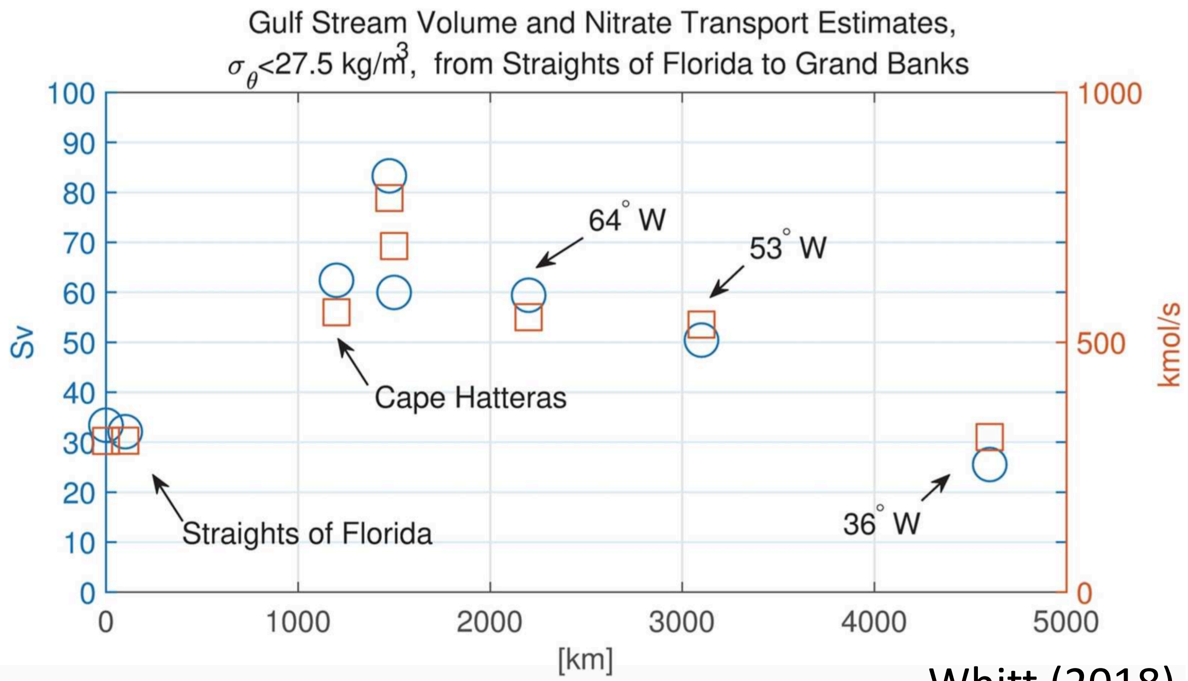
Straits of Florida

σ_θ =27.5 kg/m³

Separated Gulf Stream



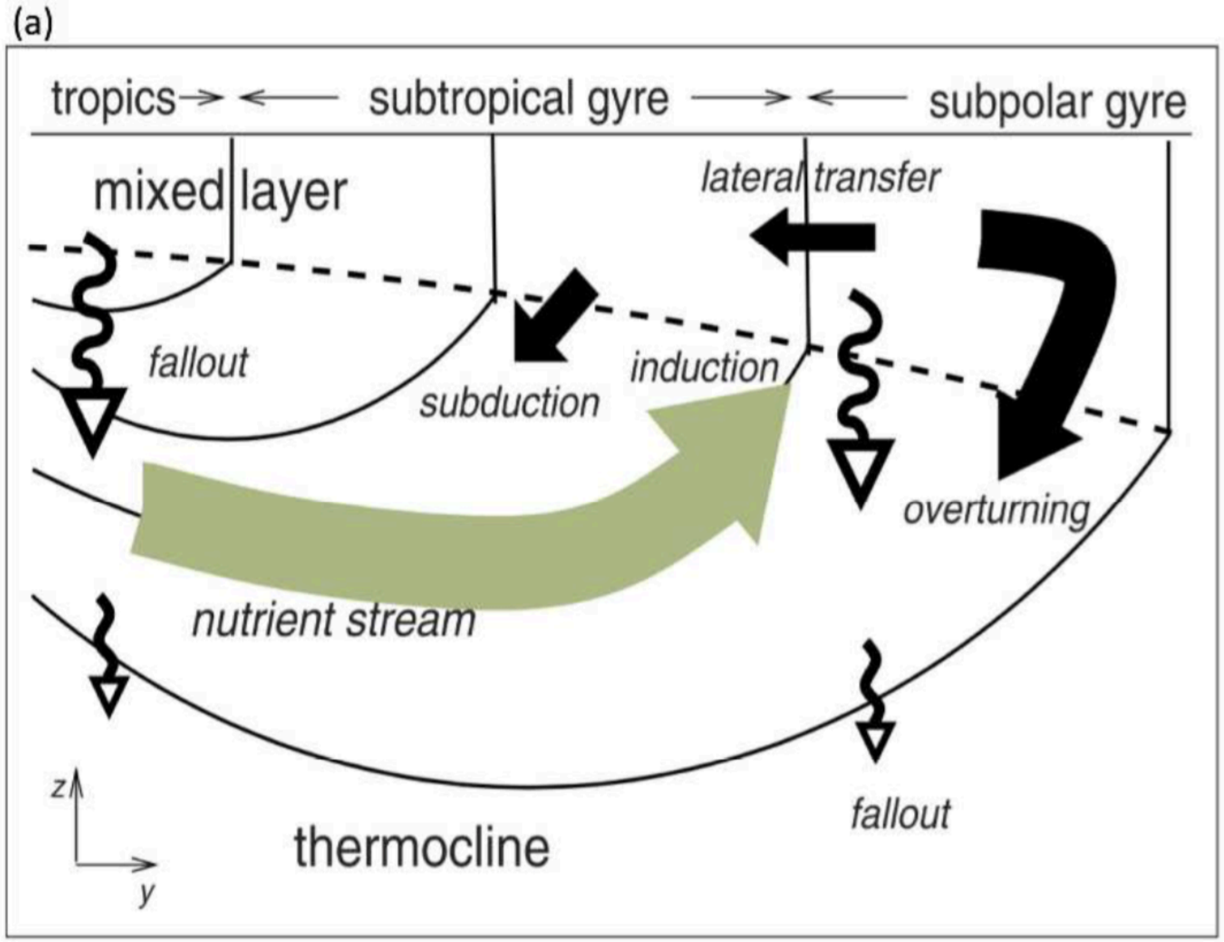
Williams et al. (2011)



Whitt (2018)

Nutrient transport highly correlated with volume transport

Fate of Gulf Stream nutrients depends strongly on their depth/density class



Williams et al. (2006)

Deeper waters irrigate subpolar gyre, shallower waters irrigate gyre boundary

Scaling key terms in the mean nitrate budget of the subpolar gyre above σ_θ =27.5 kg/m3

- Gulf Stream NO3 flux
  300-800 kmol/s
- AMOC NO3 flux
  350 kmol/s at 36 N
- Interior diapycnal nitrate flux
  < 10 kmol/s
- Entrainment
  50-75 kmol/s

Whitt (2018)

Hypotheses and motivating questions

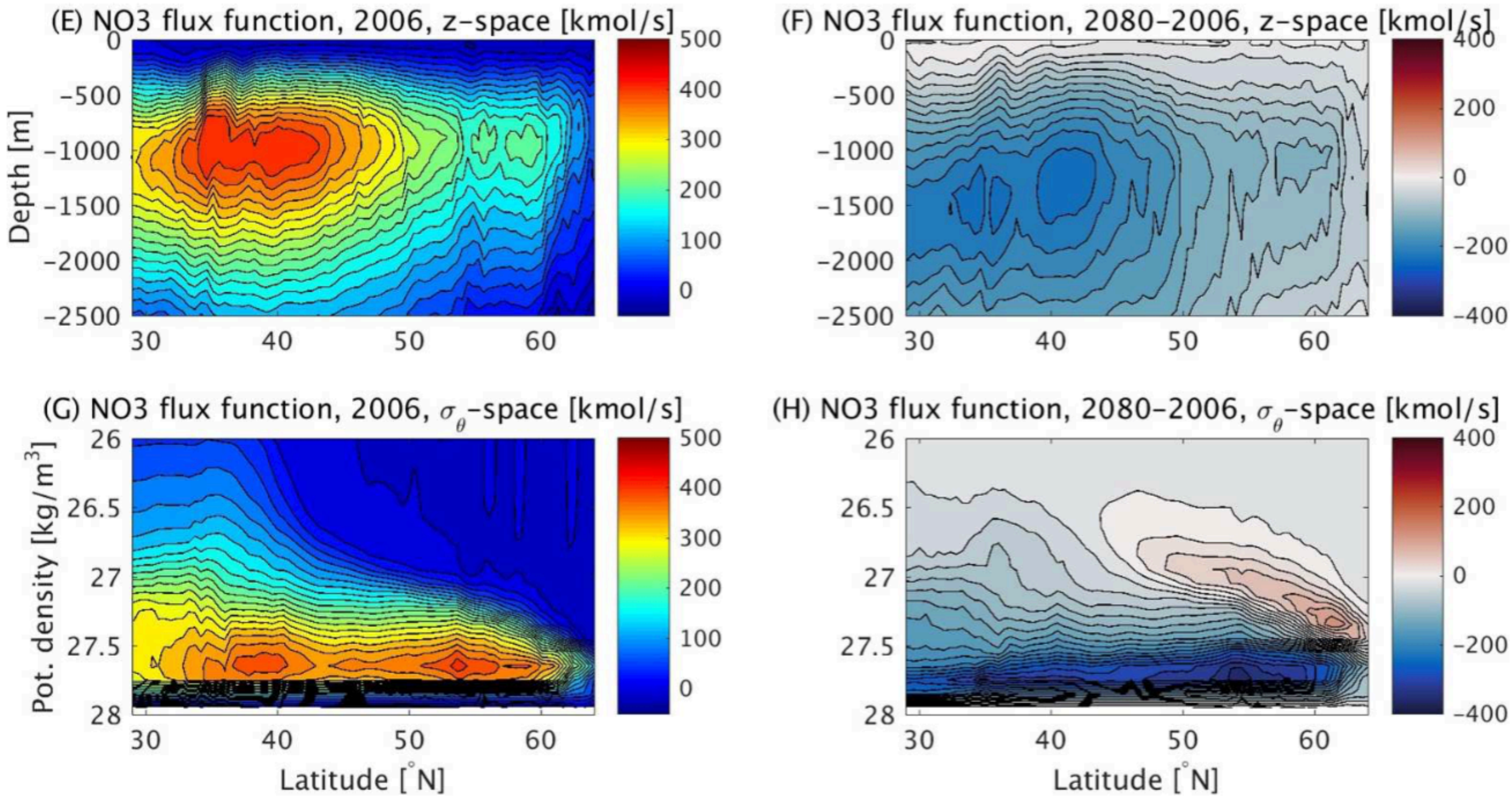
Upper-ocean ($\sigma_\theta < 27.5$ kg/m^3) NO_3 sourced from south via AMOC (~80%) and entrainment via deep convection (~20%) in the subpolar N. Atl.

How much will 21st century declines in
(1) AMOC and
(2) deep convection
drive declines in nutrient supply to the euphotic zone and export via sinking organic particles during the 21st century?

Can we separate the two effects?

Whitt (2018)

CESMLE projects that AMOC nutrient and volume transport decline by ~0.5% per year on average between 2006 and 2080



Ensemble means (34 members)

Whitt (2018)

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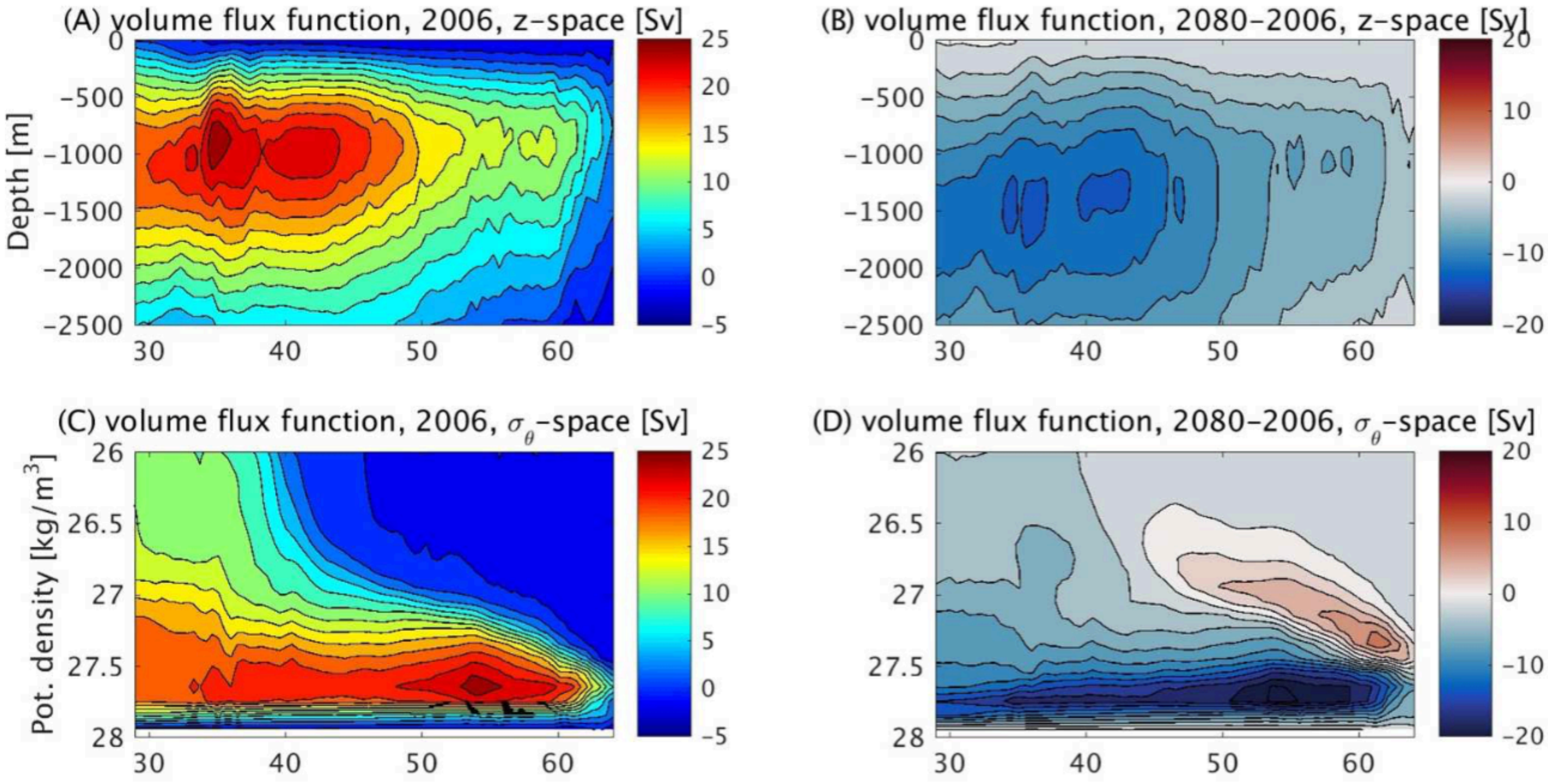

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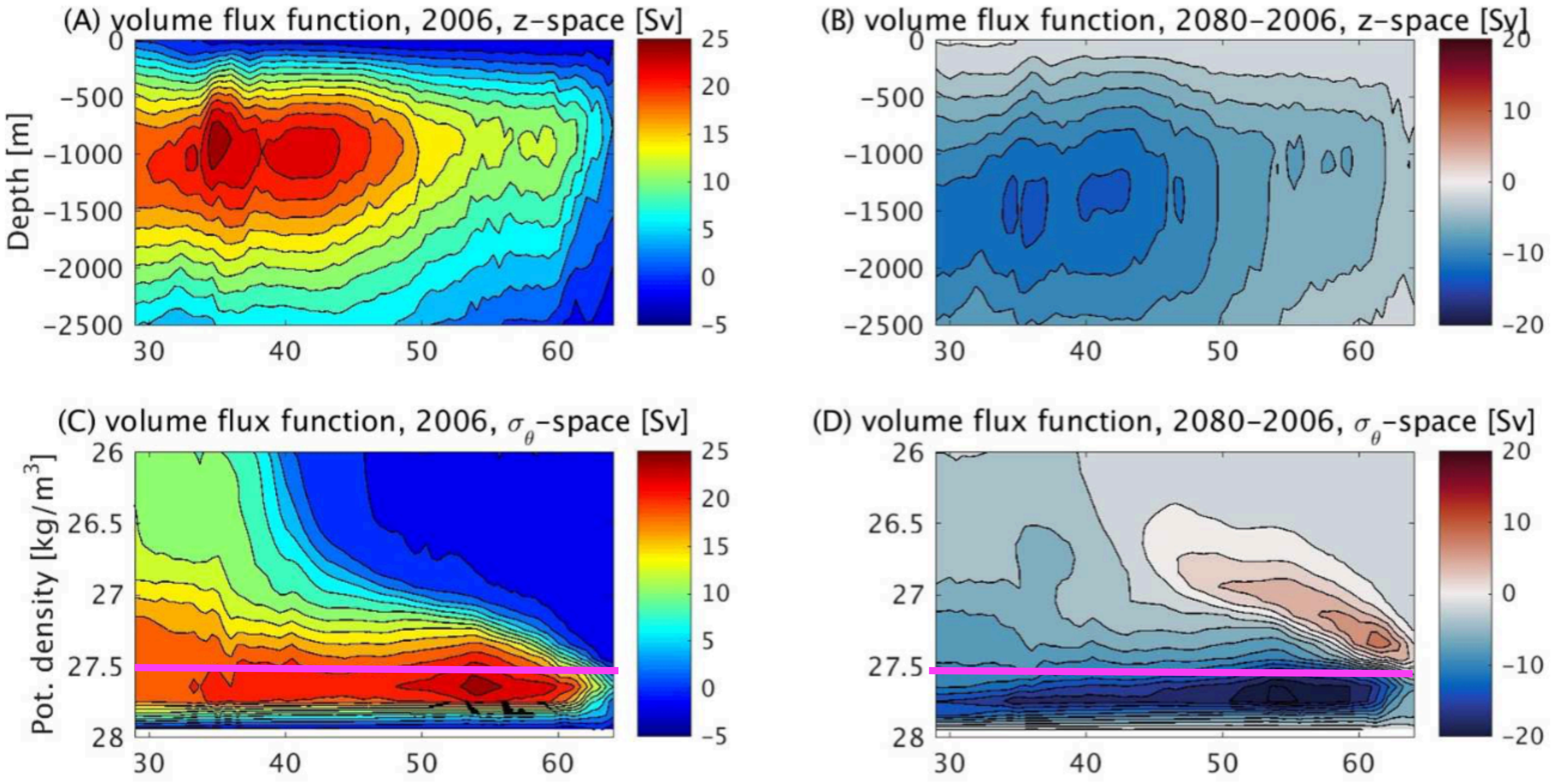

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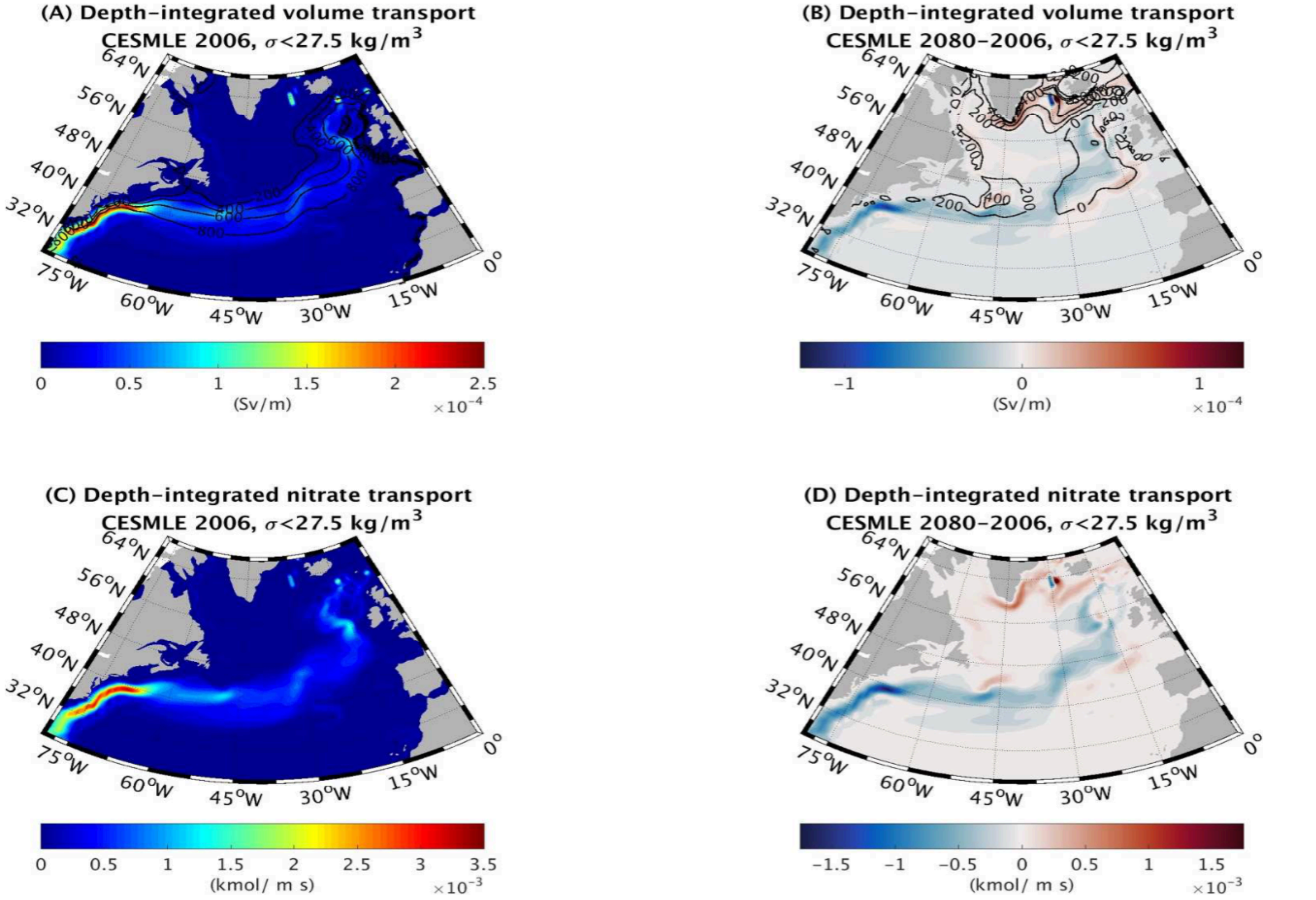
Whitt (2018)

Changes in AMOC associated with changes in Gulf Stream



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Whitt (2018)

Changes in AMOC associated with changes in Gulf Stream

Zonal integrals across Atlantic at 48 N, $\sigma_\theta < 27.5$ kg/m³

Year	AMOCN	AMOCV
	kmol/s	Sv
2006	[303, 313]	[18.3,19.3]
2080	[169, 184]	[10.9,12.0]
percent change	-43%	-39%
rate of change	-1.8 /yr	-.10 /yr

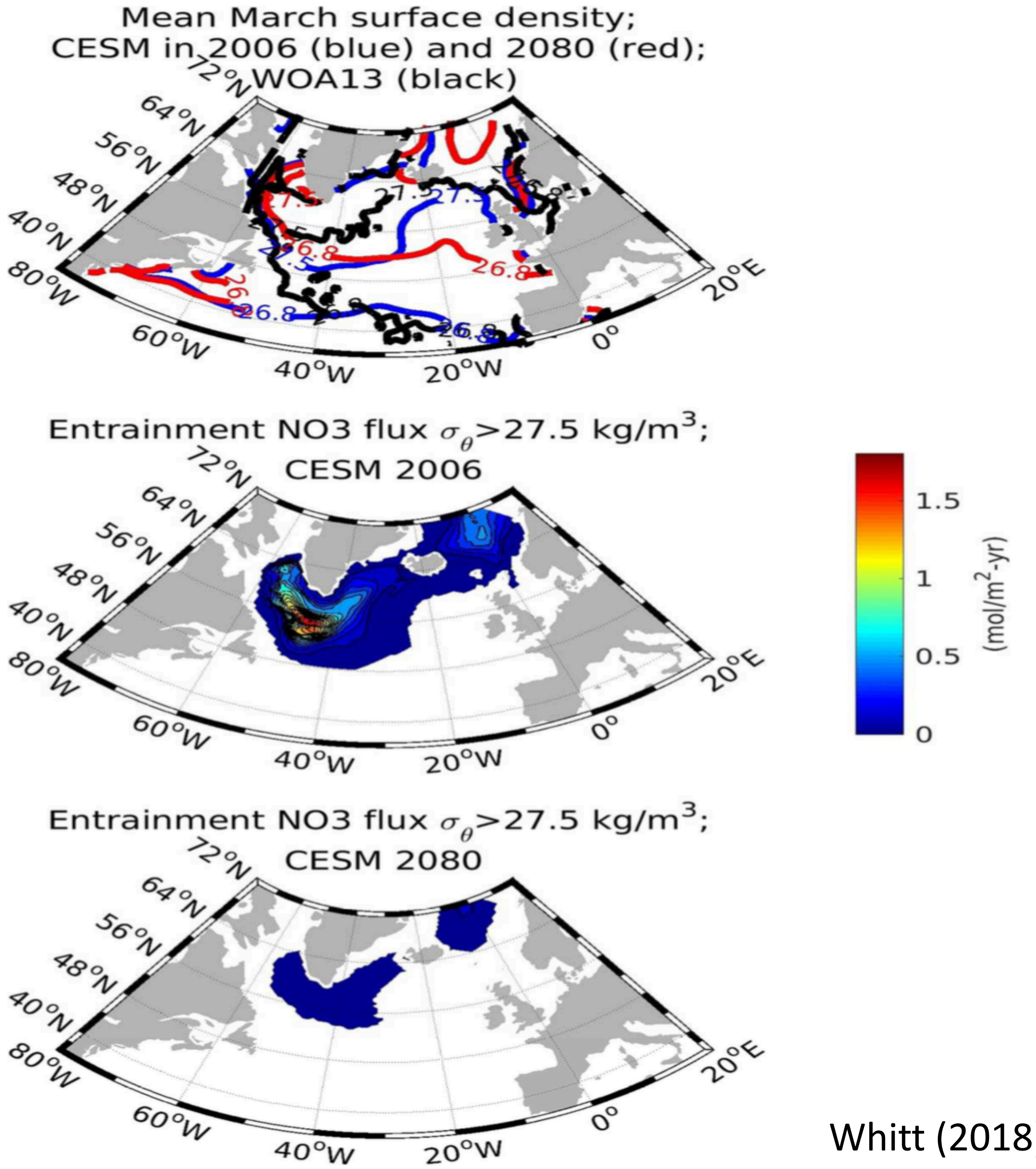
Ensemble IQRs
(34 members)

Sections across the Gulf Stream

GS,64°W,N	GS,30.5°N,N	GS,64°W,V	GS,30.5°N,V
kmol/s	kmol/s	Sv	Sv
[521,547]	[507,528]	[35.9,37.6]	[36.8,38.8]
[337,366]	[330,347]	[26.6,28.5]	[28.7,30.0]
-34%	-35%	-25%	-22%
-2.4 /yr	-2.4 /yr	-.13 /yr	-.11 /yr

Whitt (2018)

CESMLE projects near collapse of entrainment across 27.5 by 2080 in RCP8.5



Whitt (2018)

CESMLE projects near collapse of entrainment across 27.5 by 2080 in RCP8.5

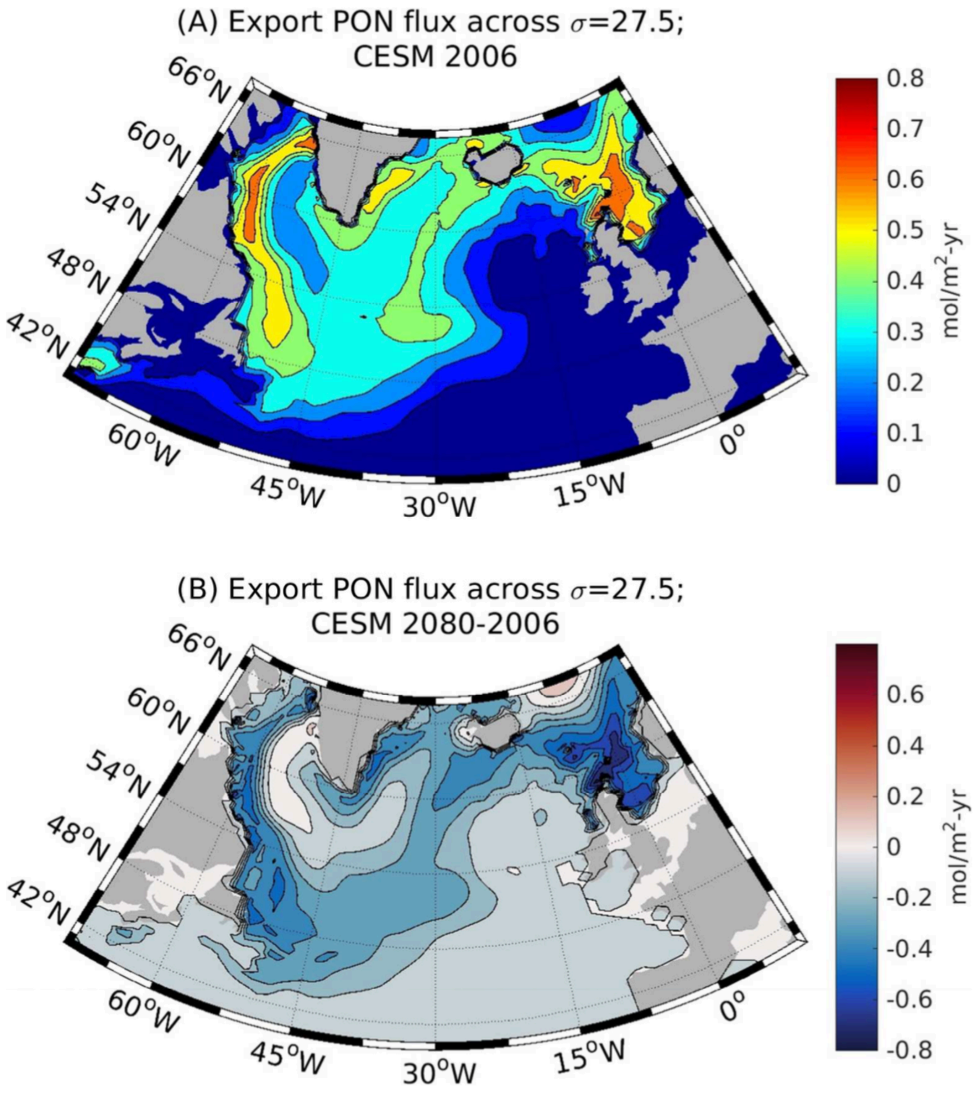
Atlantic, north of 48 N

Year	EN275
	kmol/s
2006	[27.7, 42.7]
2080	[0.8, 2.4]
percent change	-95%
rate of change	-.44 /yr

Reduced entrainment of NO3 is about 4x smaller than reduced AMOC advective NO3 flux

Whitt (2018)

Declines in NO3 supply are associated with declines in export



Pattern of reduced PON flux across 27.5 differs qualitatively from pattern of reduced NO3 entrainment across 27.5

Whitt (2018)

Declines in NO3 supply are associated with declines in export

Atlantic, north of 48 N

Year	PON275	PON100
	kmol/s	kmol/s
2006	[76.8, 81.9]	[118,123]
2080	[32.6,40.2]	[85,90]
percent change	-54%	-27%
rate of change	-.57 /yr	-.44 /yr

Reduction in export across 27.5 (~42 kmol/s) is greater than reduction in entrainment across 27.5 (~32 kmol/s)

Whitt (2018)

Key uncertainties associated with ocean physics and priorities for future research

Nutrient transport highly correlated with volume transport; CMIP5 models predict 15-60% reductions in AMOC over 21st century, so results are uncertain at an O(1) level.

O(1) uncertainties associated with ocean circulation could arise from missing mesoscale dynamics, for a variety of reasons.

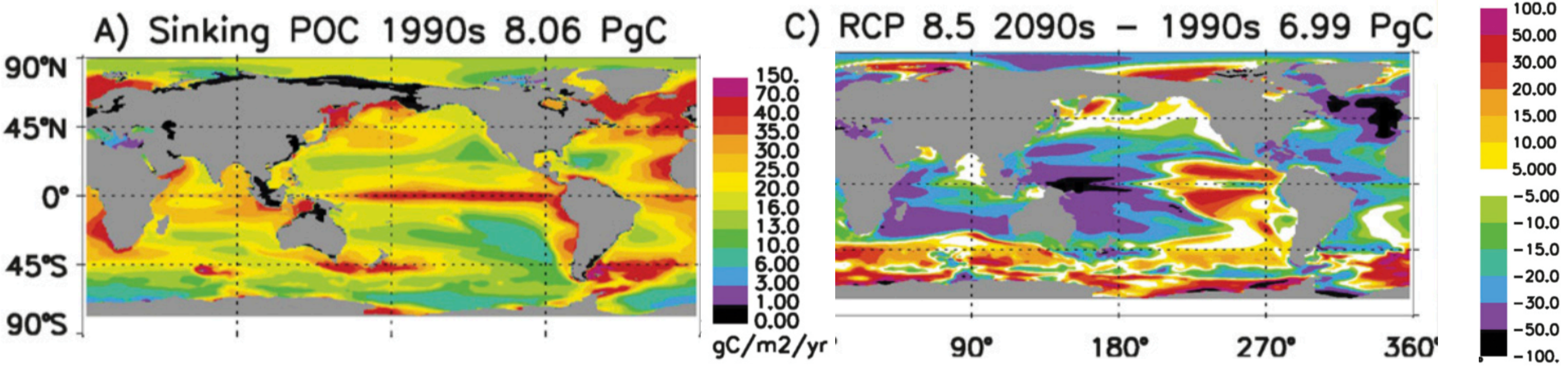
However, uncertainties about boundary layer and interior mixing processes are more likely smaller O(<10%) uncertainties, but non-negligible

Whitt (2018)

Thanks

danielwhitt.github.io

Future projections of global export of POC in CESM1



Moore et al. (2013) At 100 m

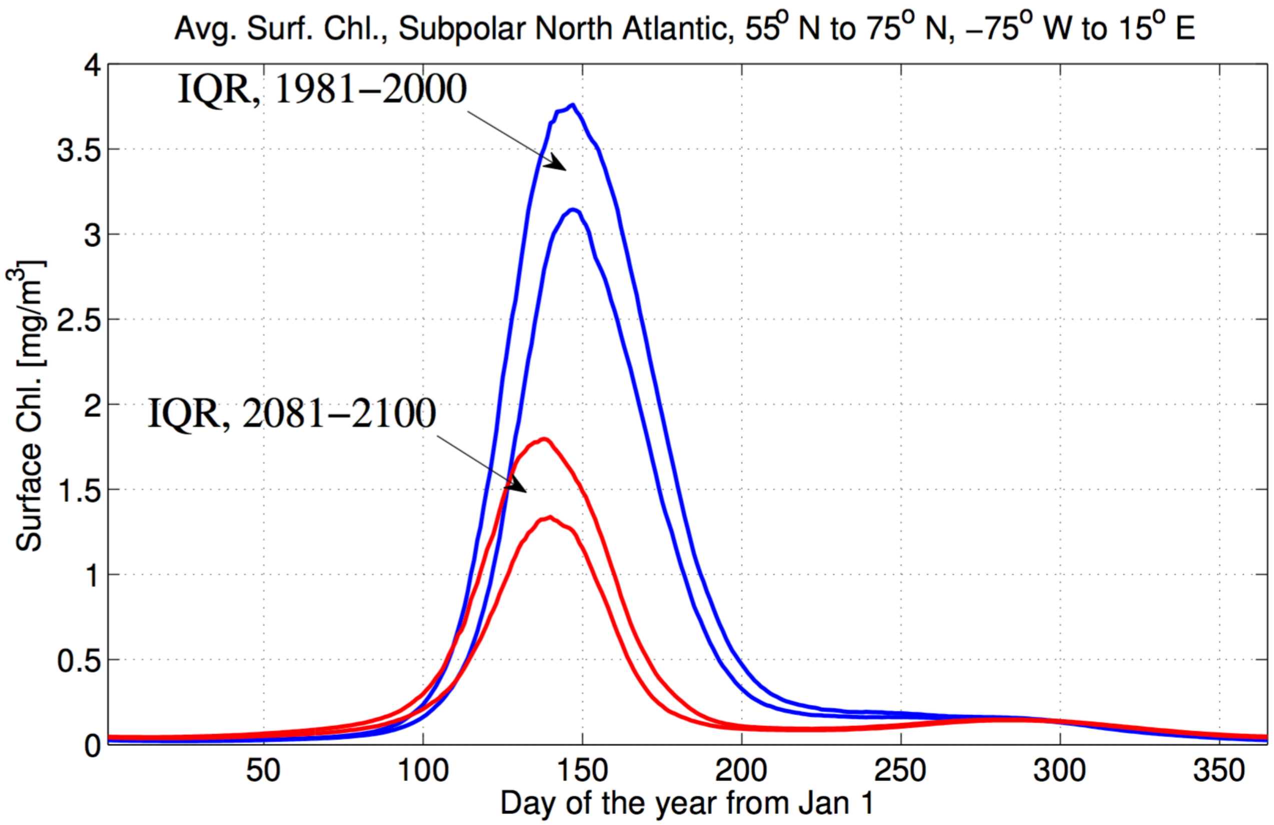
In RCP8.5, CESM1 predicts:

- enhanced export at subpolar latitudes
- reduced export at subtropical latitudes

However, subpolar North Atlantic experiences largest regional reduction in export

Dramatic reductions in phytoplankton during the North Atlantic spring bloom in RCP8.5

CESM1 Large Ensemble (34 members)

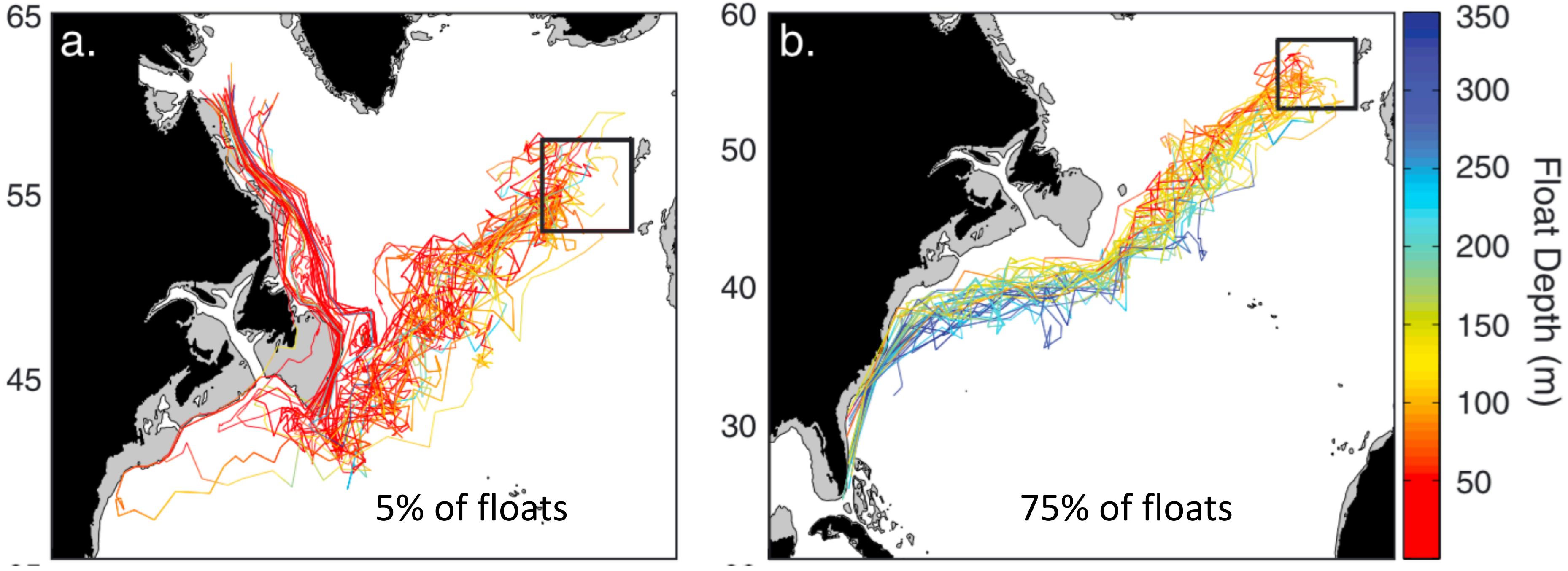


There are implicit implications for higher trophic levels, which depend on timing and magnitude of bloom

Source water for subpolar gyre water is largely sourced from deeper depths in the subtropics and is nutrient rich

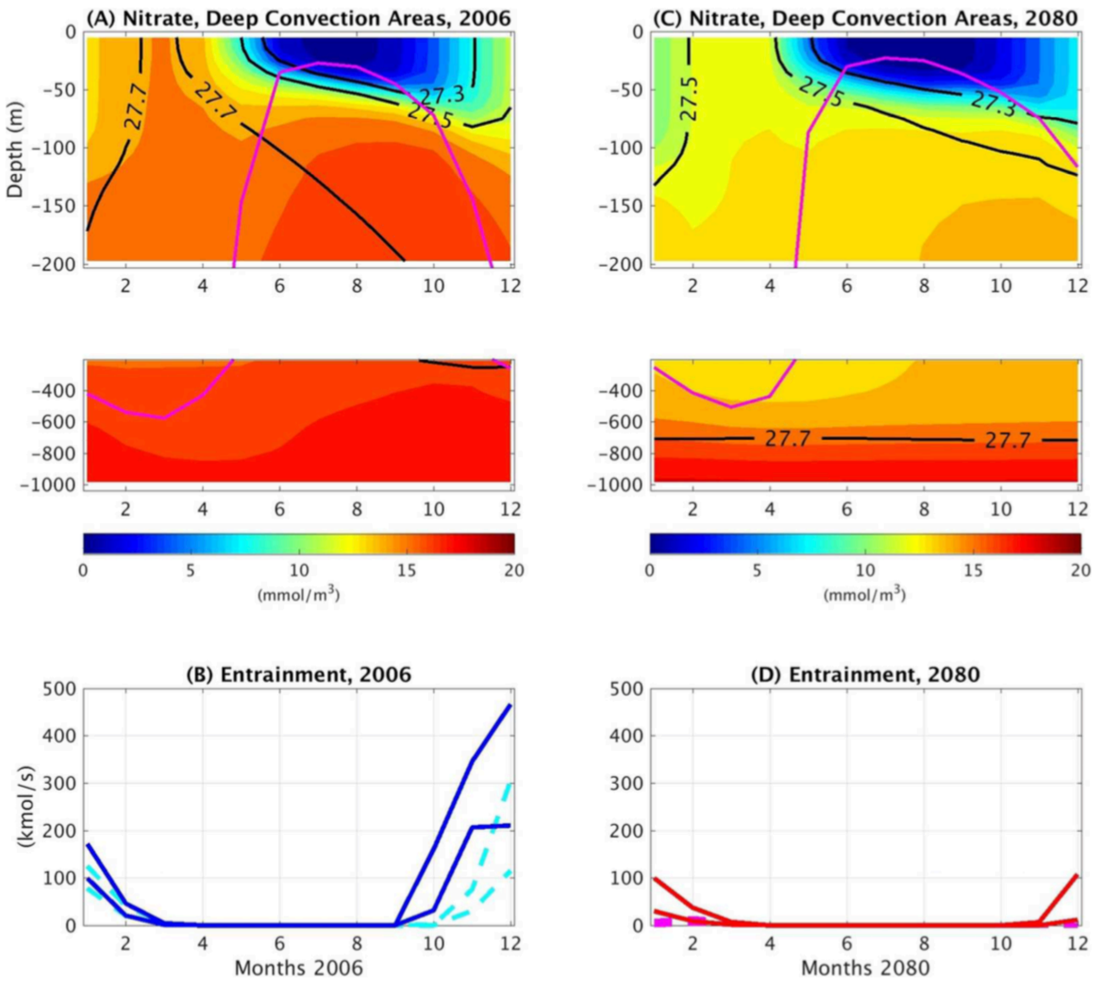
4-year back trajectories, 50 m depth

Modeled Lagrangian float trajectories in eddy-resolving model (FLAME)



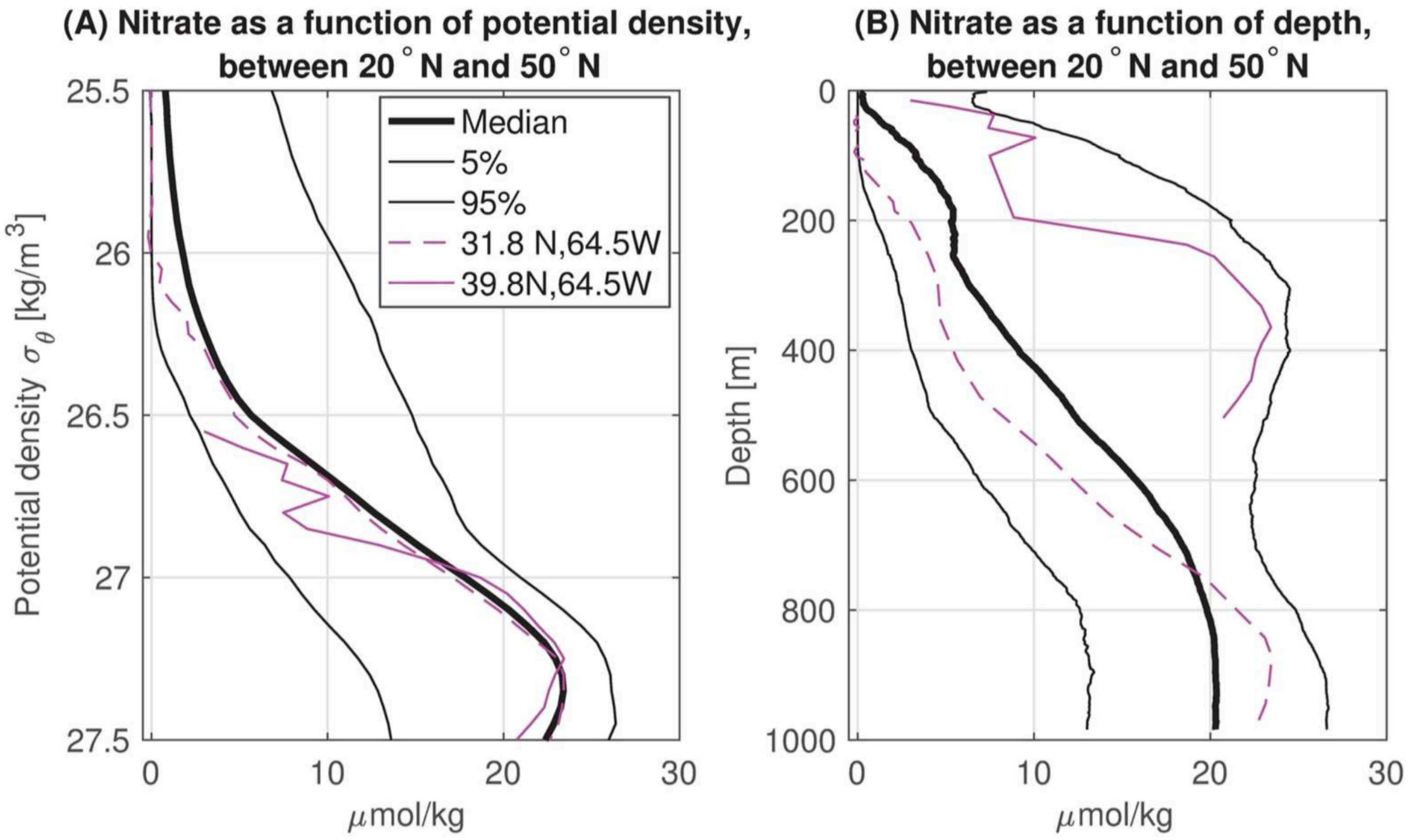
Burkholder and Lozier (2014)

CESMLE projects almost complete collapse of wintertime entrainment across 27.5 by 2080 in RCP8.5



Whitt (2018)

Gulf Stream nutrient transport key component of Atlantic nutrient circulation: observations

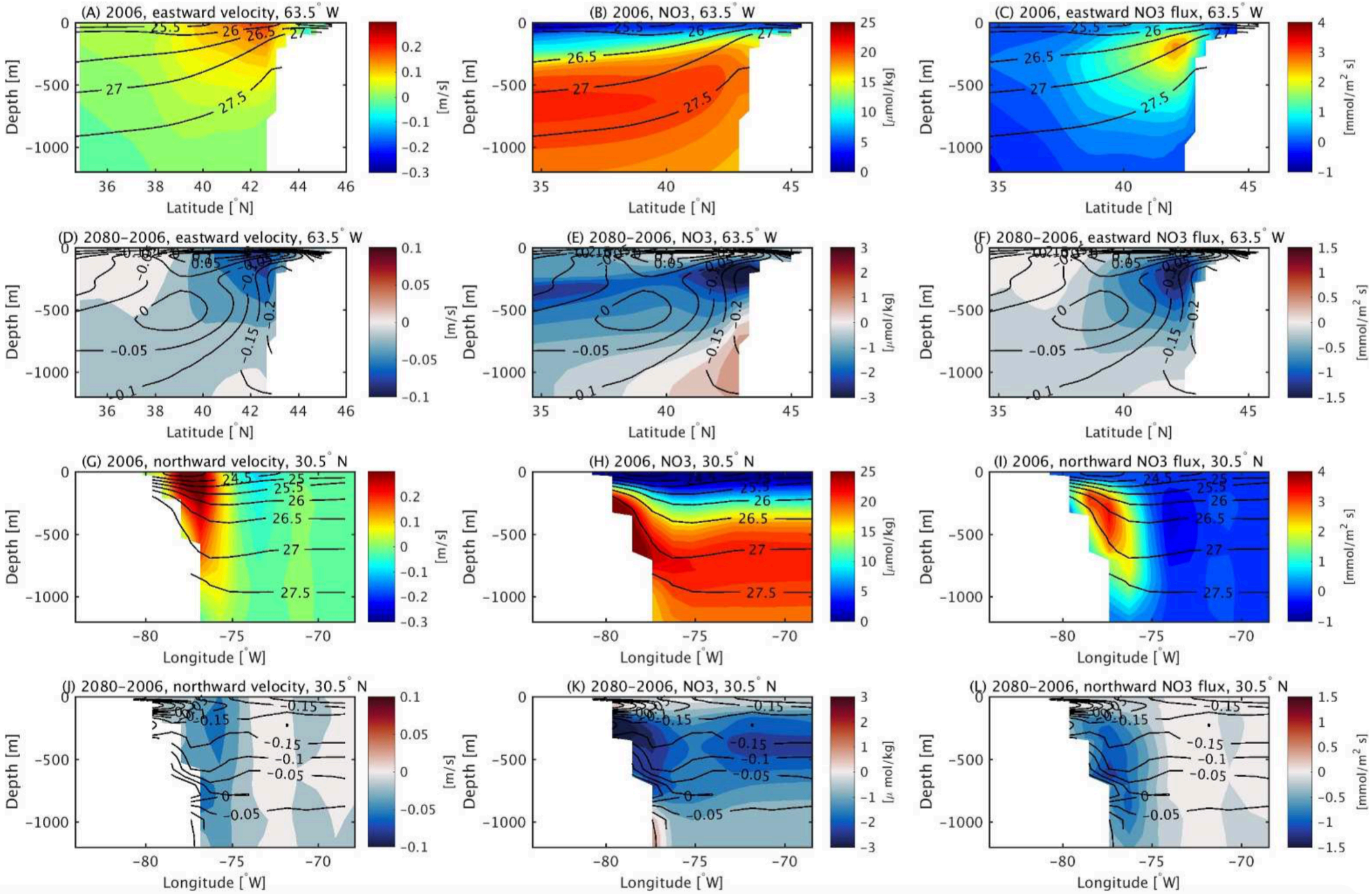


Whitt (2018)

Characteristics of the nutrient distribution:

- Vertical profiles are very different north and south of the Gulf Stream
- But nearly identical when plotted as a function of density

Changes in AMOC associated with changes in Gulf Stream



Ensemble means (34 members)

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