Biogeochemistry questions to motivate ASTE-BGC

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ECCO Annual Meeting
Our carbon goes to either the ocean or the atmosphere
Total ocean anthropogenic carbon accumulation to 1994

Using multiple tracers, estimate the additional carbon in the ocean due to human activities in 1994

Sabine et al. Science 2004
Sabine and Tanhua, ARMS, 2010
North Atlantic oxygenates the deep ocean

$O_2$ on $\sigma_2=36.9$
Global carbon fluxes and their variability
Models converge to a global mean CO$_2$ sink, but differ regionally

1982-2011 Regional CO$_2$ Fluxes
Dots = CMIP5, Star = CESM LENS

McKinley et al. 2016 Nature
HINDCAST MODELS
Blue = 8 Hindcast models
Black = Hindcast model median (used in budget)

DATA PRODUCTS
Orange = Rodenbeck et al. 2013, 2015
Pink = Landschutzer et al. 2014, 15, 16

Models all less variable than data-based estimates. Which correct?
When can emission cuts be distinguished given sink variability?

- Observations
- Reconstructed
- 1.0%/yr (Paris)
- 0.0%/yr
- -1.0%/yr

Black = Observed Atmospheric Growth Rate
Gray = Reconstruction (Emission–Land–Ocean)

Standard Deviation(Gray – Black) = 3 GtCO₂/yr

Peters et al. 2017 Nature Climate Change
North Atlantic carbon flux trends
Surface \( pCO_2 \) data, as \( CO_2 \) flux proportional to \( \Delta pCO_2 \)

Bakker et al. 2016 ESSD
Sabine et al. 2013 ESSD
Non-zero $\Delta pCO_2$ trend indicates $CO_2$ flux change

\[ \frac{d}{dt} \Delta pCO_2 > 0 \]
DECLINING SINK

\[ \frac{d}{dt} \Delta pCO_2 < 0 \]
GROWING SINK

Fay and McKinley (2013) GBC
Fay and McKinley (2014), ESSD
Fay et al. (2014) GRL
Lovenduski et al. (2015) GBC
North Atlantic $pCO_2$ data 1990-2006 trend

$pCO_2^{ocean}$ Trend
($\mu$atm/yr)

DECLINING SINK

ATM = 1.8

Schuster et al. 2009, DSR
Fay and McKinley, 2013 GBC
N. Atlantic Subpolar, Observed $\Delta pCO_2$ trends
North Atlantic sink under influence of Arctic melt
$\text{CO}_2$ sink declines as surface freshens through 2100 (CESM LENS)

Ridge et al., in prep

Freshening coherent with flux shutdown

Same coherent SSS and $\text{CO}_2$ flux changes in CMIP5 models
North Atlantic biological trends
Mean Biomass (left); Biomass trends 1998-2007 (right)

(a) SeaWiFS biomass (mgC m\(^{-3}\))
1998–2007 mean
(b) Model biomass (mgC m\(^{-3}\))
1998–2007, 0–100 m mean
(c) SeaWiFS biomass (mgC m\(^{-3}\) yr\(^{-1}\))
1998–2007 trend
(d) Model biomass (mgC m\(^{-3}\) yr\(^{-1}\))
1998–2007 trend

McKinley et al. 2018
Biogeosciences
Nutrient flux convergence trends drive eastern subpolar biomass

Vertical

(a) Vertical phosphate flux convergence (mmol m⁻³ yr⁻¹)
1998–2007 trend

(b) Horizontal phosphate flux convergence (mmol m⁻³ yr⁻¹)
1998–2007 trend

Vert+Horiz.

(c) Physical phosphate flux convergence (mmol m⁻³ yr⁻¹)
1998–2007 trend

(d) Biological phosphate flux convergence (mmol m⁻³ yr⁻¹)
1998–2007 trend

Horizontal

Biological

McKinley et al. 2018
Biogeosciences
**ASTE-BGC Motivation**

- Assess mechanisms of carbon and biogeochemical variability in the North Atlantic
- Understand impacts of Arctic change
- ....
Depth of $\sigma_2=36.9$
Salinity trend (PSU yr$^{-1}$) 2006-2100

(a)

CMCC-CESM  CNRM-CM5  CanESM2  GFDL-ESM2G

GFDL-ESM2M  GISS-E2-H-CC  GISS-E2-R-CC  HadGEM2-ES

IPSL-CM5A-MR  MIROC-ESM-CHEM  MPI-ESM-MR  NorESM1-ME
Air-sea CO$_2$ flux trends (mol C yr$^{-1}$ yr$^{-1}$) 2006-2100